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LECTURES in AEROSPACE MEDICINE

1962

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Lectures in  
**AEROSPACE  
MEDICINE**

8-12 JANUARY 1962

SCHOOL OF AEROSPACE MEDICINE  
*of the*  
AEROSPACE MEDICAL DIVISION

Flight Test

## LECTURES IN AEROSPACE MEDICINE

8 thru 10 January 1962

**HELD AT**  
**SCHOOL OF AEROSPACE MEDICINE**  
**USAF AEROSPACE MEDICAL DIVISION (AFSC)**  
**BROOKS AFB, TEXAS**

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## C O N T E N T S

<u>PRESENTATION</u>	<u>PRESENTED BY</u>	<u>PAGE</u>
WELCOME ADDRESS	Theodore C. Bedwell, Jr.	1 - 6
HISTORY AND BACK-GROUND OF ASTRONAUTICS	Paul A. Campbell	7 - 20
OCCUPATIONAL MEDICINE AT THE LAUNCH SITE	Raymond A. Yerg	21 - 44
SELECTION & STRESS TESTING OF ASTRONAUTS	Lawrence E. Lamb	45 - 64
BIOLOGIC EFFECTS OF HIGH ENERGY PRACTICES IN SPACE	Gerrit L. Hekhuis	65 - 76
PHYSIOLOGIC NECESSITIES IN SIMULATED LUNAR FLIGHTS	Billy E. Welch	77 - 96
BIOMEDICAL MONITORING IN-FLIGHT	James A. Roman	97 - 114

C O N T E N T S (Continued)

<u>PRESENTATION</u>	<u>PRESENTED BY</u>	<u>PAGE</u>
WEIGHTLESSNESS: A PHYSIOLOGICAL PROBLEM IN SPACE	Bruce H. Warren	115 - 134
NEWER ASPECTS OF SUBCELLULAR PHOTOSYNTHESES	Daniel I. Arnon	135 - 158
BIO-INSTRUMENTATION FOR SPACE FLIGHT	Ray W. Ware	159 - 172
WHAT CAN MAN CONTRIBUTE TO OPERATIONS IN SPACE	Robert Y. Walker	173 - 190
X-15 OPERATIONS IN PRE-LUNAR STUDIES	Robert M. White	191 - 210
RESPONSE OF MAMMALIAN SYSTEMS TO NON-UNIFORM SPACE RADIATION DOSE	Charles Sonnhaus	211 - 240
BIO-ASTRONAUTIC SUPPORT OF THE X-15 & DYNASOAR	Bert Rowen	241 - 256

C O N T E N T S (Continued)

<u>PRESENTATION</u>	<u>PRESENTED BY</u>	<u>PAGE</u>
INTERPLANETARY ENVIRONMENT	Robert Jastrow	257 - 276
EXTRA "TERRESTRIAL LIFE"	Stanley L. Miller	277 - 298
* PROPULSION SYSTEMS FOR LUNAR OPERATION	Geoffrey Robillard	299 - 300
OCULAR EFFECTS OF PARTICULATE SPACE RADIATION	James F. Culver	301 - 326
MONITORING OF MOON BASE ATMOSPHERES BY GAS CHROMATOGRAPHY	Thomas B. Weber	327 - 346
THE ECOLOGIC PROFILE OF THE MOON	Hubertus Strughold	347 - 356
SOIL-LESS GARDENING ON THE MOON	Hans G. Clamann	369 - 384

C O N T E N T S (Continued)

<u>PRESENTATION</u>	<u>PRESENTED BY</u>	<u>PAGE</u>
THE LUNAR CRUST FOR LIFE SUPPORT	Jack Green	385 - 432
WHO OWNS THE MOON?	Thomas A. Taggart	433 - 446
* THE LOGISTICS OF RE-LAUNCH FROM THE MOON	Krafft A. Ehricke	447 - 448

\* Those articles marked with an asterisk (\*) were not available for publication.

## WELCOME

By

Brig Gen Theodore C. Bedwell, Jr., USAF, MC

General Bedwell is the Commander, Aerospace Medical Division. He received his B.S. from S.M.U.; his M.D. from Baylor University; and his M.P.H. from the Johns Hopkins School of Hygiene and Public Health. He has had post-graduate training in Industrial Medicine at Harvard School of Public Health. He is a Fellow of the Aerospace Medical Association, the American College of Preventive Medicine, and Royal Society of Health, and has membership in several other national professional organizations. He is certified by the American Board of Preventive Medicine in Aviation Medicine, Public Health and Occupational Medicine. He is rated a Chief Flight Surgeon.

Presented at the Lectures in Aerospace Medicine  
Held 8-12 January 1962  
School of Aerospace Medicine

## WELCOME ADDRESS

By

Brig Gen Theodore C. Bedwell, Jr., USAF, MC

It gives me a great deal of pleasure to welcome such a large assembly for the 1962 Lectures in Aerospace Medicine.

This is the third year that the lecture series has been presented by the School of Aerospace Medicine. Each year the attendance is larger and more representative of the many agencies with an interest in the field of Bioastronautics.

Your response to the series has been a source of much gratification to the School, to the Aerospace Medical Center as a whole, and now to the Aerospace Medical Division of the Air Force Systems Command. The central purpose in each layer of our present organization is the same. It is to acquire and disseminate the fullest possible knowledge of the functions and behavior of man in space, as well as in the earth's atmosphere.

You may be interested in the origin of this course of lectures. As many of you know, the School of Aerospace Medicine has a background of research and teaching in the medical problems of human flight that reaches back to 1918, when military aviation was in its infancy. For many years, this was the only institution engaged in studies of that kind.

As the altitude, the range, and the speed of flying vehicles increased, the scope of our studies naturally became broader. As early as 1946, when the rocket-powered Bell X-1 was being tested at Edwards Air Force Base, we were already looking toward the possibility of orbital and even interplanetary space craft.

The Department of Space Medicine was established at the School in February 1949. For a number of years, it was uniquely occupied in making serious investigations of the medical problems of space flight. The press and the public followed its findings with interest, intermixed with a certain amount of tolerant amusement. To a large extent, it was ignored by other scientific and aeronautical agencies.

**Welcome****Brigadier General Theodore C. Bedwell, Jr.**

Since 1957, when the first Soviet sputnik appeared in the sky, the situation has been radically altered. Now a good many other institutions participate in space research to a greater or lesser degree. Today, every significant advance in the art of maintaining man in space is awaited with intense curiosity, and critically reviewed by all segments of the scientific-technological community.

Until 1959, as a teaching organization, the School was concerned primarily with keeping Air Force medical officers and flight surgeons abreast of the many new discoveries and techniques in this field of practice. Our Primary Course in Aerospace Medicine provided a reasonably thorough survey of recent developments in space research. Quite a few graduates of the primary course, when they completed their military service, went on to initiate similar studies of their own in industry, in universities, or in other government agencies.

We also had and still have an Advanced Course in Aviation Medicine. It is for career medical officers, planning to take their specialty board examinations in this area. And, finally, we had a review course for practicing flight surgeons in this field. Its purpose was to bring them up to date in the latest information on effects of high-altitude, high-speed flight and related problems.

After we moved over here to Brooks in 1959, and established the Aerospace Medical Center, we found that we had facilities for a somewhat wider teaching effort than the limited one we had carried on at Randolph Air Force Base. It was realized that the School of Aerospace Medicine, in its forty-odd years of research, had stored up an unparalleled background of knowledge, discriminating judgement, and experience in sustaining flight at the borders of the atmosphere and beyond. We felt that this background should be made available to other agencies which were now entering the same field.

So, in January 1960, we undertook this lecture series for the first time. It was designed specifically for medical research personnel in aerospace industry, for professors in medical schools, and for selected laymen, including members of the press who were assigned to report on space technology and operations. Besides, it is addressed to non-medical administrators, both military and civilian, who are active in the management of Bioastronautics programs.

**Brigadier General Theodore C. Bedwell, Jr.**

In my opinion, the lectures have shown themselves to be a valuable way to widen the knowledge of recent progress in the human aspects of space flight. Their success amply justifies our effort to extend this knowledge beyond the boundaries of Air Force Medicine.

Our invariable objective in the course is to explore the areas of greatest interest and importance at the time it is given. As you would expect, there have been substantial changes in the content of the lectures over the past three years. From a generalized picture of the space medium and its medical effects, the progression has been toward specific operational problems and goals.

Three years ago, we gave much of our attention to the biophysics of the aerospace environment, and to celestial bodies including the sun, the nearer planets, and the moon. A good part of the program dealt with basic studies of radiation, of acceleration forces, propulsion systems, the composition and control of cabin atmospheres, and surveys of the space programs then projected or under way.

Much of this material now has become so well known that it can be taken for granted. Instead, this year we concentrate to a large extent on actual medical conditions encountered in space flight activities at this time - for example, in selecting astronauts, in monitoring their performance, or in weighing the data obtained from manned test vehicles, such as the X-15 and the two suborbital mercury capsules which were sent aloft over the Atlantic in 1961.

We are now embarked on a definite program to place a party of American astronauts on the moon before the end of this decade, and perhaps as early as 1967. So a considerable portion of the current lecture series is devoted to lunar problems. They include specific medical effects which can be expected during the flight and the landing, conditions on the surface of the moon, and tentative experimental results to be obtained by the expedition.

One of the major paradoxes of our time has been brought about by the rapid progress of recent years in science and technology. A vast amount of new and vital knowledge about matter and

**Welcome****Brigadier General Theodore C. Bedwell, Jr.**

its behavior has been uncovered. But the products of research are so numerous and so scattered that they pose a formidable problem simply to assemble and digest those which are relevant to one's own work.

The Lectures in Aerospace Medicine are an attempt to deal with this problem in one field of science and technology. They offer an important advantage over the many scientific meetings which are scheduled nowadays in that the material is collected by research specialists and reduced to an orderly presentation once a year.

The School of Aerospace Medicine is able to perform this service because it is a teaching facility as well as a research institute. We carry on this activity anyway for our Air Force medical officers and technicians. So it is with added satisfaction that we offer the same material to others, like yourselves, who have a similar need for this kind of knowledge.

The entire staff of the Aerospace Medical Division joins me in making you welcome here at Brooks. We are glad to have you with us, and we hope that you will gain as much benefit from the course as we derive by presenting it.

## HISTORY AND BACKGROUND OF ASTRONAUTICS

By

Colonel Paul A. Campbell, USAF, MC

Colonel Campbell is a member of the Advanced Studies Group, Aerospace Medical Division. He earned his Sc.B. at the University of Chicago and his M.D. at Rush Medical College of the University of Chicago. He has had post-graduate medicine at the University of Vienna. He holds membership in numerous professional societies. He is certified by the American Board of Otolaryngology and American Board of Preventive Medicine (Aviation Medicine). He is a Fellow of the American Medical Association, Aerospace Medical Association, American Astronautical Society, and British Interplanetary Society. He is rated a Chief Flight Surgeon.

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Soon an era of expanded science and technology will culminate in rather commonplace space travel. Thus, it is extremely interesting to study the diverse roots which have nurtured the developments and which, in turn, have made such an event possible. The roots dip their tendrils into many disciplines. Each and every student of the history of astronautics will undoubtedly have his own idea of the roots, their courses, and the greatness of their contribution. Mine are encompassed in Figure 1. The top root is that of the contributions of astronomy and related subjects which have formed the background for astronautics. The second root has to do with the communicators; those who through one medium or another, in one way or another, communicated ideas, research and philosophy, or just encouragement to others. The third root encompasses the science and technology of rocketry, whose reaction principle and capability of carrying its own oxidizer gave man, for the first time, a vehicle effective above the atmosphere and capable of travel in the vacuum of space. The fourth root is that of aeronautics, and the fifth, that of medicine, biology, and related subjects which have been extended through aviation medicine into space medicine.

Let us begin with the line of which astronomy has been the major contributor. The mythology of all the peoples of the Earth contain references to the heavenly bodies whose nightly splendor they held in awe--either worshiping the celestial bodies or fearing them. The Babylonians gave their Moon Goddess the lovely name of Cynthia from which our word Sin has derived. The cereal growers of the Earth: Babylonia, Egypt, China, Japan; the Incas, Maya and Aztec populations--all recognized the existence of a correlation between the nightly parade of the constellations with growing seasons, flooding of rivers, etc. The annual parade of the constellations gave them a calendar in the heavens; the changes in the Moon, their time of month, and the movement of the Sun, their time of day. The calendars which have sprung up with each of the early civilizations reflect these changes. If the movements of the constellations could predict the events of the Earth so, too, they reasoned, could they predict the events of man. Thus, the astrologer came into being, furnishing his predictions and hoping he was right. In the early days the astronomer was the handmaiden of the astrologer, furnishing the data from which the astrologer's predictions or fabrications could be fashioned from whole cloth.

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\*The contents of this paper reflect the personal views of the author and are not to be construed as a statement of official United States Air Force policy.

## History and Background of Astronautics Colonel Paul A. Campbell

About the year 540 B. C. a Babylonian exchange student was instrumental in founding a school of astronomy on the Greek island of Cos. Here the so-called Saros, a cycle of 223 lunations requiring a period of 18 years and 11 days, during which the moon returns almost precisely to its same place in the heavens, was determined. The knowledge of this cycle made eclipse predictions possible and began the demonstration of Nature's orderliness--the backdrop from which the laws of Nature began to emerge.

Pythagoras of Samos (540 B. C.) during his travels to Egypt and the East, learned much to bring back to his fellow star-gazers. Aristarchos of Samos proposed that the Sun was the center of a planetary system which revolved around it--a true belief, which was lost through the Dark Ages until Copernicus revived it many, many centuries later. Aristarchos was followed by a succession of the greats: Eratosthenes, Hipparchus, Ptolemaeus, Aristotle, and Plato. One can tell who is really great by looking at the names of lunar landmarks. Each of these has his name firmly engraved on the map of the Moon.

Let us look at a few of the Greats of the time and point to their contributions:

### THE GREEKS

Circa 600 B.C.: Anaximander specified the Earth to be a sphere.

Circa 250 B.C.: The Greek, Eratosthenes, measured the circumference of the Earth to be 24,647 miles--an error of some 1%.

Circa 150 B.C.: Hipparchus measured the distance to the Moon as 33 Earth diameters--an error of possibly 3 Earth diameters.

Now let us turn to the early communicators, as shown in the second rootlet, who began to think of voyages which might take them away from their mundane drudgery up to celestial bodies, furnishing adventure, new experiences, and possibly a better life. The ancient legends of almost all peoples whose early history is in any way documented contained the seeds of the concepts of space flight. The legends then gave way to travelogue mythology.

In the year 160 A.D. Lucian of Samosta wrote what was probably the first novel on an extraterrestrial voyage. In his book, "Vera

## History and Background of Astronautics

### Colonel Paul A. Campbell

11

"Historia," a ship was flung up by a waterspout and arrived on the Moon 7 days and 7 nights thereafter. In a second book by the same author titled, "Icaromenippus," the hero planned his navigation very carefully after much study of the stars. He took off in a vehicle propelled by the wing of an eagle and one of a vulture. Mount Olympus was the point of take-off. He reached the Moon and then used it as a station in space to stage from, reaching Heaven on the third day. He then got into trouble with the immortals, was taken back to Earth and stripped of his wings, so he could not participate in further cosmic events.

Mixing astronomy with science-fiction probably began with Plutarch when he wrote his book, "De Facie in Orbe Lunae," translated, "On the Face that Can be Seen in the Orb of the Moon." Plutarch knew the Moon to be a solid body and, according to his treatise, was inhabited by the souls of the dead.

Now came a gap of fourteen centuries in which, so far as can be determined, no great book such as that of Lucian or Plutarch had been written. The era of enlightenment was at hand. Columbus had just performed the greatest feat of serendipity of all times--he had accidentally discovered the backside of the Earth. Now occurred the great astronomical revolution led by Copernicus\* with his book, "On the Revolutions of Celestial Orbs," written in 1543; Kepler's treatise, "On the Motion of Mars," 1609; and Galileo's, "Messenger of the Stars," appearing in 1610. These men were true astronomers and astrophysicists, and they had the means of communicating their knowledge, as the printing press was in being and in operation.\*\* Copernicus described the revolution of the planets around the sun in what he thought to be circular orbits. Kepler, using the data of Tycho Brahe, his preceptor, then demonstrated the courses to be ellipses, and Galileo with his newly fabricated telescope, the "optick" tube, demonstrated the planets to be bodies possibly not unlike the Earth. Old astronomy became new astronomy with this famous group. Of Kepler's famous laws, the first stated that planets travel around the sun in ellipses with the sun as one focus. His second law set forth that the radius vector swept equal areas in equal times thus explaining some of the basic physics and mathematics of orbits. His third law dealt with distance and time relationships. These were the laws

\*Copernicus had been trained as a physician and was court physician for a period.

\*\*Footnote: The printing press with movable type appeared in Germany circa 1450.

## History and Background of Astronautics

Colonel Paul A. Campbell

of the movements of satellites and hold for the movements of man-made satellites, as well as natural ones. He, in fact, was the first to use the term satellite.

Arthur Koestler points out an interesting bit of side information. Kepler was a bear for mathematical accuracy and to prevent any doubt about his origin he furnished the following information in his horoscope: He was conceived on 16 May 1571 at 4:37 A.M. and was born 27 December, immaturely, after a pregnancy lasting 224 days, 9 hours, and 53 minutes. He was not so accurate about some other matters, as he himself spelled his name five different ways.

Kepler's great book of fact and fantasy the "Somnium," is another example of the place of science-fiction in progress toward manned space flight and one of the great factors which has led us to the point at which we have arrived today--that of preparing a man to orbit the earth. The Somnium was well known to the later-day science-fiction writers including Jules Verne and H. G. Wells. The title of the book, when translated, is "The Dream," and uses a dream theme to convey new knowledge and concepts which could complicate his already troubled life, were they to be identified as Kepler's\* studies. Much of the book is masked autobiography. It purposely did not appear in print until four years after Kepler's death, but several of his contemporaries apparently had read it in manuscript form several years before his death. Persecution was the lot of those who sought to tell any truth which might run counter to the dogma remaining as a carry-over from the Dark Ages into the dawn of the era of enlightenment. Copernicus, Kepler and Galileo were persecuted throughout much of their lives. Like the Greeks, they often resorted to the dialogue--double talk if you please, to get their ideas across but protecting the first person.

Many books and much new knowledge followed. Godwin, Cyrano de Bergerac, \*\* Bernard de Fontenelle, Voltaire, Swedenborg, and others wrote on the subject. These and many others, brought the literature--much of it sheer fantasy, but often prophetic--up to the time of Jules Verne, whose books, "From the Earth to the Moon," and, "Around the Moon," written 96 years ago, excited the imagination of the people of the earth. This strange union of science and fiction is of especial interest to us here and now.

\*Kepler wrote a friend concerning "Somnium." "My book will be useful to emigrants and pilgrims as a guide book to the Moon."

\*\*Cyrano de Bergerac was first to mention the use of rocket propulsion for space voyage, using a box with several rockets attached.

In Verne's books the Civil War had just been concluded; ballistics as a science had matured. Verne, a Frenchman who had never visited America, felt only the Americans had enough money for the multimillion dollar project. He knew that because of the ecliptic the take-off place had to be beneath the 28th parallel. This narrowed the activities of the site selection board down to Texas and Florida. Oil had not been as yet discovered in Texas, and Florida through power politics won.

Jules Verne's man-carrying projectile took off from Florida 27 degrees 7' N. Lat. and 82 degrees 7' W. Long. This places the point in the area of Tampa, as the crow flies, only 120 miles from Cape Canaveral. Ardan--his hero, wit, conversationalist, and bon vivant--was probably the French newspaperman Nadar, with his name spelled more or less in reverse. Nadar, to add a little more confusion, was born Tournachon and under that name took the first aerial photographs. He had been educated as a physician. Whatever he was, his knowledge of physiology was good and he must have been very helpful to Verne. The monitoring station was Long's Peak, Colorado; the telescope a reflector of about 204 inches. The monitor, himself, was from Cambridge Observatory.

The oxygen requirement for their capsule containing three men, according to their calculations, was 2400 liters per day, to be produced by 28 pounds per day of potassium chlorate. Caustic potash was used to remove carbon dioxide. To test their life-support system one of the prospective astronauts was sealed in the newly fabricated cabin for a 7-day dry run--remember Airman Farrell! Jules Verne's subject was unable to contact the outside in any way due to the thickness of the walls. This was isolation. On exit at the end of the 7th day the only physical change was, and I quote, "He had grown fat." So also had Airman Farrell(3 pounds). Of interest was the arrangement for shock absorption during take-off and landing. It consisted of a series of water cells with collapsible partitions. Their positioning was on their sides. This was all pretty good 96 years ago.

Organizations for study of manned space flight came into being in the early part of the twentieth century and were both sounding boards and spring boards for novel ideas. The organizations include, among others: the Verein für Raumfahrt of Germany, founded in 1927; The American Interplanetary Society, founded in 1930; and the British Interplanetary Society, founded in 1933. The space effort owes a great debt of gratitude to these groups as they kept alive--at times in spite of ridicule--the basic concepts in which they believed, and in most cases did not hesitate to pour sufficient fuel on the flames to keep the pot boiling--sometimes with an explosive violence.

## History and Background of Astronautics

Colonel Paul A. Campbell

Many, many bits and pieces of knowledge had now accumulated in many arts and sciences to make space flight possible. Sir Isaac Newton (1642-1727) had extended the concepts of Copernicus, Kepler, and Galileo. He had set forth his law of universal gravitation, and his reaction principle had pointed to the possibility of traveling through empty space by means of rockets.

So, let us have a look at the development of rocketry.\* The Chinese had fireworks, probably before the birth of Christ. Rockets used as fire arrows were chronicled in the 13th Century A. D. (1232). Around the year 1500 A. D., according to the Chinese, an official named Wan-Hoo, fastened two kites to a saddle arrangement and then placed 47 large powder rockets around various strategic points. He then positioned himself and the rockets were ignited according to a prearranged signal. After they were ignited the official disappeared in a blast of fire and smoke, never to be seen again. The Chinese have missed a famous "first" here, as he may have been the first man in orbit, and may still be there.

Rockets appeared in and out of history, utilized mostly for amusement and weapons. As we all remember, our National Anthem was written by the "rockets red glare." New impetus, however, came from the experiments of the now famous Dr. Robert Goddard, who was born in 1882.

Now begins an interesting era as far as a background for space flight is concerned. It involved three men, although there were other "greats" at the time. These men were Dr. Robert Goddard, who has just been mentioned; Konstantin Eduardovich Tsiolkovskii of Russia; and Hermann Oberth of Roumanian-German-Transylvanian extraction. In my estimation these three men, collectively, did for the mechanics of space flight, all Copernicus, Kepler, and Galileo had done for celestial mechanics. None of the three appeared to have known of the work of the others until about 1922. They seemed to have worked independently. The only common denominator I can find is that they were all avid readers of Jules Verne. Each made great contributions, but the magnitude of the contributions have been acknowledged only in retrospect, as several years elapsed in each case before the implications of the work widely grasped.

\*Webster's Dictionary says the term Rocket came from the Italian "roccetta" which, in turn, was derived from "rocca," a Teutonic distaff which it resembled.

## History and Background of Astronautics Colonel Paul A. Campbell

15

Tsiolkovskii and Oberth were theoreticians while Goddard was an experimental physicist--the only one of the three actually producing experimental data. Tsiolkovskii was probably the first of the group, but his work on the theoretical possibilities of space flight lay buried\* until Oberth's work was known. Tsiolkovskii's work was then republished. Oberth's work, "The Rocket in Interplanetary Space," set forth a feasible plan for space flight. This was enlarged upon in his later work. He had an excellent understanding of almost all the problems, including those of physiological and psychological nature. His works had great influence on the group of young German scientists who formed the rocket experimental group, first at Reinickendorf and later at Peenemunde, the well known German Rocket Center.

Dr. Robert H. Goddard became Professor of Physics and Director of the Physical Laboratories of Clark University in 1919. His great book, "A Method of Reaching Extreme Altitudes," was written in the same year. He was destined to be the father of modern rocketry, although he, too, was recognized mostly in retrospect. His motor and guidance mechanism used liquid propellant, a gyro stabilizer, and movable exhaust vanes--all innovations of the time.

Now we must turn back a little to pick up the progress of the astrologers and the astronomers, as our vehicle for space flight was now approaching the final stage of development. Orbital and escape velocities were well known. The propellants and the vehicles were on the horizon. It now required an art or a science to utilize the coasting vehicle spent of most of its energy, other than kinetic, that it might move off into other orbits, following the laws of celestial mechanics. So let us now bring up the name of Hohmann.

Dr. Walter Hohmann, City Architect of Essen-on-the-Ruhr, wrote another poor seller, a contemporary of Oberth's book, entitled, "The Attainability of the Celestial Bodies." Even in German, I understand, it is pretty rugged reading. However, he discussed:

Part I                  Departure From the Earth

Part II                  Return to Earth

— \* Oberth could not read Russian, according to Willie Ley, p. 112. Prof. Goddard could not read Russian either, so far as can be determined. Willie Ley cites some interesting history of the era in his splendid book, "Rockets, Missiles and Space Travel," published by the Viking Press.

**History and Background of Astronautics****Colonel Paul A. Campbell,**

Part III	Free Coasting in Space
Part IV	Circular Orbits Around Other Celestial Bodies
Part V	Landing on Other Celestial Bodies

He demonstrated, mathematically, that energy requirements for travel from one planet to another could be held at a minimum if advantage was taken of the rotation of the earth for launch, rotation of the planets about the sun resulting in optimal position distance-wise and attraction between the bodies for bending flight paths, etc.

As energy for space flight is certainly one of the most important limitations of manned space travel, his calculations have been extremely important, especially from the standpoint of logistics.

Now let us consider the fourth root--that of aeronautics. In 1638 John Wilkins, one of the founders of the Royal Society of England and, incidentally, Cromwell's brother-in-law, wrote an excellent book, "Discovery of a New World in the Moon." He described four methods of flight: first, by spirits or angels; second, by help of fowl; third, by wings fastened immediately to the body; and fourth, by a flying chariot. For our purposes we might pass over the first three and get directly to the flying chariot idea--but an unsuspected device, the balloon, entered the picture here and took precedence over the flying chariot in the introduction of aeronautics. Balloons of a sort have been mentioned since the time of Charlemagne and the early eras of Chinese culture; however, from a practical point of view the art and sciences began with the Montgolfier brothers, Joseph (1749-1810) and Jacques (1745-1799), when they wondered what would happen if they captured a cloud in a bag. Their inquisitiveness led them first to hydrogen. They wished to use a paper bag but found that paper was permeable to hydrogen. Then they decided to try smoke. Their balloon first ascended over Annonay, France, June 5, 1783; however, the first manned flight awaited Jene-Francois Pilatre de Rozier (1756-1785) a surgeon and apothecary, a "truant" of Aesculapius, on October 15, 1783. His first ascent was in a captive balloon. He was also the first martyr to aeronautics, as he died when his hydrogen balloon exploded on an attempt to cross the English Channel in the reverse direction of Dr. John Jeffries and Blanchard, June 15, 1785.

The sky now was full of errant doctors. Dr. Edward Jenner (1749-1823), future discoverer of vaccination, constructed the first balloon in Gloucestershire, England. Leonhard Euler (1707-1783)

## History and Background of Astronautics Colonel Paul A. Campbell

17

of Basle, student of medicine, and later the great mathematician; Dr. James Tytler (circa 1747-1805); Dr. George Fordyce (1736-1802) and a Dr. Black, about whom little is known, were among these.

The art and science of balloon flights continued along the path of history well known to most of us. We will speak of just two more events here, both of which are important in the development of astronautics. The first was the Anderson and Stevens\* balloon flight in Explorer II, Nov. 11, 1935, to an altitude of 72,395 feet, during which they studied cosmic rays, electrical conductivity of the atmosphere, vertical distribution of ozone, composition of the stratosphere, brightness of the sun, earth, and sky, and microorganisms in the atmosphere.

The second was that of our Lt Col David Simons, who on August 19 and 20, 1957 soared for 32 hours and 10 minutes, suspended from a 3,000,000 cu. ft. balloon. The maximum altitude reached was 101,516 feet. He studied human reactions in the closed capsule, cosmic radiation, horizon and sky luminance, physiological factors, night visibility, astronomical visibility, etc. His work is well known to all of us.

The history of aviation, beginning with the flight of the Wright Brothers in 1903, is well known to all of us and, consequently, needs no mention at this time.

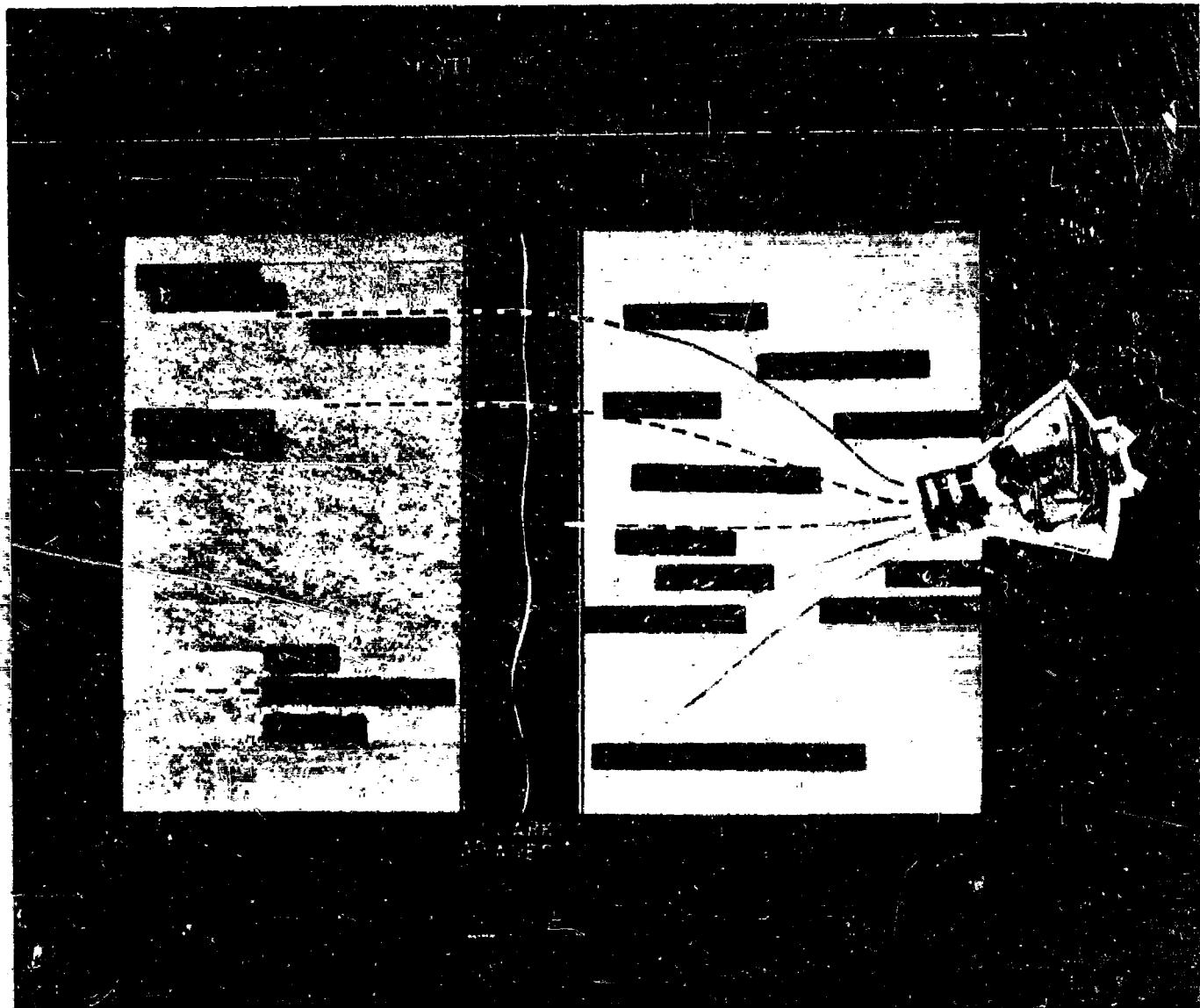
The final root of our sequence is that of medicine and physiology, with its extensions into Aviation and Space Medicine. The basic structure was built firmly on the foundation afforded by numerous physicians and scientists who were cross-trained in physiology, biology, physics, astronomy, and engineering, and who I have mentioned in the preceding pages. We thus must add to the list of "greats," the name of Paul Bert (1833-1886), who studied the reactions of the aeronauts, Croce-Spinelli and Sivel, in a low pressure (altitude) chamber, and later the records of their ill-fated flight with Tissandier. We must mention the chemist, Charles, as well as the physicists, Gay-Lussac and Humbolt. These and many others bring us to our own time. Only one more daring than I would delve into this history.

In conclusion, one must point out that the magic date recurring through mythology, science, and space fiction for man's first visit to celestial objects has been in the neighborhood of the year 2000 A.D. Most of us, who are optimists, feel that date will be moved up by several years.

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\*Anon. "The National Geographic Society, U. S. Army Air Corps Stratosphere Flight of 1935 in the Balloon, Explorer II." National Geographic Society, Washington, D. C., 1936.

18 History and Background of Astronautics  
Colonel Paul A. Campbell,



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### Colonel Paul A. Campbell

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## OCCUPATIONAL MEDICINE AT THE LAUNCH SITE

By

Colonel Raymond A. Yerg, USAF, MC

Colonel Yerg graduated from Georgetown University School of Medicine and received his M.P.H. from Harvard School of Public Health. He first entered military service in 1943. In 1951 he returned to full time military duty as a member of the Nevada Air National Guard. On nine occasions he has received military service medals. Air Force honors have included the Air Force Commendation Medal. He is a Diplomate of the American Board of Preventive Medicine in Aviation Medicine.

Presented at the Lectures in Aerospace Medicine  
Held 8-12 January 1962  
School of Aerospace Medicine

## OCCUPATIONAL MEDICINE AT THE LAUNCH SITE\*

By

Colonel Raymond A. Yerg, USAF, MC

Gentlemen, it is a pleasure for me to be here this morning to speak on the occupational health problems at the launch site. I think it is appropriate to consider some of the problems which face the operators of the missile systems, because much of the success of manned space flight depends on the individuals who are operating the ground launch equipment.

In the operational situation, the Industrial Hygiene Engineer, the Flight Surgeon and Occupational Medicine Officer formed a team to investigate some of the occupational health problems in the missile complex. A program was established based on the missile systems. The fundamental systems are the propellant and guidance systems, with the hydraulic, electrical and ordnance sub-systems, (Figure 1). The occupational health problems were then related to these fundamental systems. It is within these general areas that I wish to speak during the next few minutes.

The first problem I would like to discuss is that of propellant toxicity. (Figure 2). The fuels with which we are concerned are liquid hydrogen, the hydrazine family, which is principally used in the storable configuration, and the straight chain hydrocarbon RP-1. There are some interesting things about this figure which are not completely listed. The maximum allowable concentrations are in a very low order of magnitude of 0.5 to 1 part per million in the storable propellants. However, we have also been concerned with the acute exposure levels. Recently, the National Research Council established these figures. 50 parts per million UDMH can be tolerated for a period of five minutes, 35 parts can be tolerated for 15 minutes, 20 parts for 30 minutes and 10 parts for 60 minutes. We are right now in the process of doing diffusion studies at Cape Canaveral and testing the propellant transfer systems for the Titan II system, but these results are not yet available.

The principal thing of interest, as far as the rest of the figure is concerned, other than the symptomatology, with which you are all familiar, is the medical evaluation program. Since this

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\*The contents of this paper reflect the personal views of the author and are not to be construed as a statement of official United States Air Force policy.

## Occupational Medicine at the Launch Site

Colonel Raymond A. Yerg

figure has been made, an evaluation of individuals who have participated in the handling of these propellants at Cape Canaveral has been made. Some 1900 evaluations have been done during the past three years and there has been no evidence of any toxic effects on these individuals in their normal working environment, using the standard protective equipment and safety procedures. We no longer do a complete evaluation every six months on these individuals. But, rather after having had a baseline evaluation, they are given further examinations only if there has been evidence of some acute exposure.

The same general situation applies with regard to the oxidizers. (Figure 3). Red fuming nitric acid and nitrogen tetroxide, both having their maximum allowable concentrations based on NO<sub>2</sub>. Acute exposure levels have also been established for these compounds in somewhat lesser amounts, but still allowing individuals to perform a task if the operational situation demands. With regard to the medical evaluation, we are not doing any complete evaluations at periodic intervals any longer at Cape Canaveral, but only when there has been evidence of some acute exposure.

Now, I'd like to show a few figures to indicate where these particular propellants are used, in what kind of system. This is a Thor (Figure 4), a single stage, liquid oxygen, RP-1 propelled missile. These same propellants are used in the Titan I system - liquid oxygen and RP-1. (Figure 5) This is a photograph of Titan I coming out of its silo. Titan I is a two-stage missile. It is a forerunner of Titan II which is essentially the same configuration except that it has the same diameter throughout its entire length. Titan II produces about 430,000 pounds of thrust at sea level versus Titan I, which is about 360,000-380,000 pounds. Titan II uses storable propellants; nitrogen tetroxide for the oxidizer and 50-50 mixture of hydrazine and UDMH; the oxidizer and nitrogen tetroxide (N<sub>2</sub>C<sub>4</sub>). Titan III is the booster vehicle for the Dyna Soar space program which the Air Force is sponsoring at this time. (Figure 6). The next figure is a photograph of the Agena vehicle (Figure 7) which uses unsymmetrical dimethyl hydrazine and red fuming nitric acid. The beauty of this vehicle is that it has a "start" and "stop" capability in space which is considered to be one of the primary factors as far as the rendezvous technique is concerned. When it is mounted on a booster, it has this sort of a configuration. (Figure 8). We have here the Agena vehicle, mated to an Atlas, which is the basic configuration for this program.

Now, just a few words about liquid hydrogen because it is one of our most significant fuels in the liquid area as far as our space

## **Occupational Medicine at the Launch Site**

### **Colonel Raymond A. Yerg**

25

program is concerned, and as I understand, is one of the fundamental ones on which our whole program is based. Liquid hydrogen is kept at -423 degrees F, which is very close to the absolute zero point as noted on the figure. (Figure 9). It is odorless and I think the slide produces some information which is of significance and interest to you.

Specific impulse is defined as the amount of thrust per pound second of flow. You can see that there is a considerable difference in the specific impulse of LOX and RP-1 versus LOX and liquid hydrogen. This is what makes it such a desirable fuel for space flight.

The safety rules in the handling of all of these propellants are quite similar although principally this slide relates to liquid hydrogen. (Figure 10). There is a requirement for chemical sensors of a portable type as well as fixed types. Alarm systems must be located in launch control centers and around fuel areas to protect individuals in the event that there is an accidental spill. There is another interesting thing about liquid hydrogen. Those of you who have had experience with liquid oxygen or liquid nitrogen know that you can pour it from one container to another. However, liquid hydrogen will gasify before you can actually pour it from one container into another, and this is one of the things that creates a principal hazard, namely explosion.

From a protective equipment standpoint, workers generally use these kinds of things in the handling of propellants. (Figure 11).

With regard to the storable propellants, there is an additional requirement in that individuals must be completely protected from head to foot and have an individual air supply. The Martin Company has designed a very interesting suit which they call a SCAPE suit (Self Contained Atmospheric Breathing Ensemble). It contains a liquid air supply which not only provides air to the operator, but it also provides a cooling capability.

It has a 30 minute total supply and when the liquid air reaches a level of 15 minutes, a red light flashes inside of the helmet to indicate the remaining time.

To put the propulsion systems together in a space vehicle for a moon flight, this figure (Figure 12) shows an artist's conception of SATURN C-1, which was recently launched from Cape Canaveral with a cluster of eight rocket engines producing about 1 1/2 million pounds of thrust. Actually, the new engine which is being developed is a single 1 1/2 million pound thrust engine. A cluster of four of these will produce 6,000,000 pounds of thrust. This is a liquid oxygen RP-1 system.

## **Occupational Medicine at the Launch Site**

### **Colonel Raymond A. Yerg**

Mated to it could be a Titan II using the nitrogen tetroxide and the aerozine 50 storable propellant configuration. And, mounted on top of that is the liquid hydrogen, liquid oxygen configuration to give the space vehicle its final boost.

In the area of radiation I will confine my remarks to those radiation problems which may be encountered in the actual operational configuration. (Figure 13). We are concerned with the re-entry vehicle and any radioactive material it may contain. The "Broken Arrow" definition is the capability of the Air Force to cope with peacetime nuclear accidents.

Aboard the re-entry vehicle may be a battery containing a gamma emitting radioisotope. Finally, within the airframe of the Titan, there is a thorium magnesium alloy which is a weak alpha emitter and could cause difficulty when it is involved in fire or flame.

Within the launch control center of the Atlas, there is an automatic programming and checkout unit which is an electronic computer system to check out all of the missile systems. In performing this task, there are a series of plastic cards which are inserted. To eliminate the static electricity, there is a polonium 210 bar in the machine as shown on the picture. (Figure 14). This bar is subject to chipping or flaking and is a potential source of alpha contamination.

Within the Guidance Control Center, there are two types of radiation problems. (Figure 15). The microwave radiation from the radar antenna and x-rays from the ground electronic systems. Most of you are familiar with the experience the General Electric Company had wherein individuals received rather large doses of radiation working around these tubes while they were improperly shielded.

Another area of concern is that of industrial radiography. (Figure 16). All of the missile systems operate under high pressures of 6 - 8,000 pounds per square inch to move the propellants rapidly through transfer systems and to insure that the fuel is brought to the engines in proper quantities as needed. With the solid propellant configurations there is concern about the integrity of the casing, etc.

This figure (Figure 17) presents the general medical problems of monitoring and surveillance in terms of distance, time and shielding, and also survey instrumentation, monitoring and medical evaluation.

I would like to say a few words about the noise hazards in missile operations. Within the Atlas system there is a unit called

## Occupational Medicine at the Launch Site

### Colonel Raymond A. Yerg

27

the hydraulic servicing unit. This unit located at the launch pad is used to check out the hydraulic system. The hydraulic system is one of the systems for giving the missile guidance and control, as it controls the movement of the engines in flight.

The individual who operates this equipment is exposed to noise levels of between 104 and 108 decibels. (Figure 18). The operation may be prolonged over a period of several hours. The operator must be in communication with the Launch Control Officer and Maintenance Officer in the Launch Control Center. Thus, he must perform his tasks and also must communicate and be understood. I think you can see the potential of an individual not performing his task properly after a period of time in this kind of an environment if he does not have proper protective equipment.

Another area where noise problems of considerable intensity are encountered is in the powerhouses. This is a photo of the Titan powerhouse at Vandenberg. (Figure 19). When it is in operation, the generators produce in the order of magnitude of 115 decibels. These are overall sound pressure levels. They have not been subjected completely to octave band analysis, but even so, I think the problem is evident there as far as the worker is concerned. The man may be in this environment for a long period of time, depending upon the mission requirements.

In the underground environment, where these powerhouses are located in some of the operational configurations, this could be a more serious problem. But, I have not had any experience with it myself.

Medical evaluation of the noise hazards are as listed on this next figure (Figure 20).

We are concerned, too, with some of the noise problems that may be generated by these large boosters, as far as the civilian communities are concerned. With the Saturn launch last month, the thrust was in the order of magnitude of 1.5 million pounds and the maximum decibel level about 100 feet from the missile as it was in its vertical ascent right off the pad, amounted to about 150 decibels. But, there weren't any people in this area. At the closest area where there were any people, the sound level meters peaked at about 120 decibels and rapidly fell off. Mostly, the sound levels are in the low frequencies and do not seem to present a problem at this time with that magnitude of thrust. However, studies are continuing in this area.

Selection of individuals to operate missile systems seems rather obvious and this figure (Figure 21) outlines the basic requirements. As

## Occupational Medicine at the Launch Site

Colonel Raymond A. Yerg

the national significance of our space programs increase, the requirements for highly selected operators increase.

In this final group of figures it is my purpose to illustrate the accident experience at a missile test center. The data clearly depict that there are no essential differences in the accident experience at a missile site than in any industrial operation. While specifically related to the period May 59 - April 60, recent data confirm the same trends.

The first figure in this series shows the working population and percent of accidents (Figure 22). Next, a comparison between missile and industrial accidents in general to show the general similarity (Figure 23). The next three figures compare experience between missile operations personnel and missile support personnel in terms of accident type (Figure 24), injury type (Figure 25), and body parts involved (Figure 26). As you can see, there are no significant differences in these two groups.

Occupational Medicine at the Launch Site 29  
Colonel Raymond A. Yerg

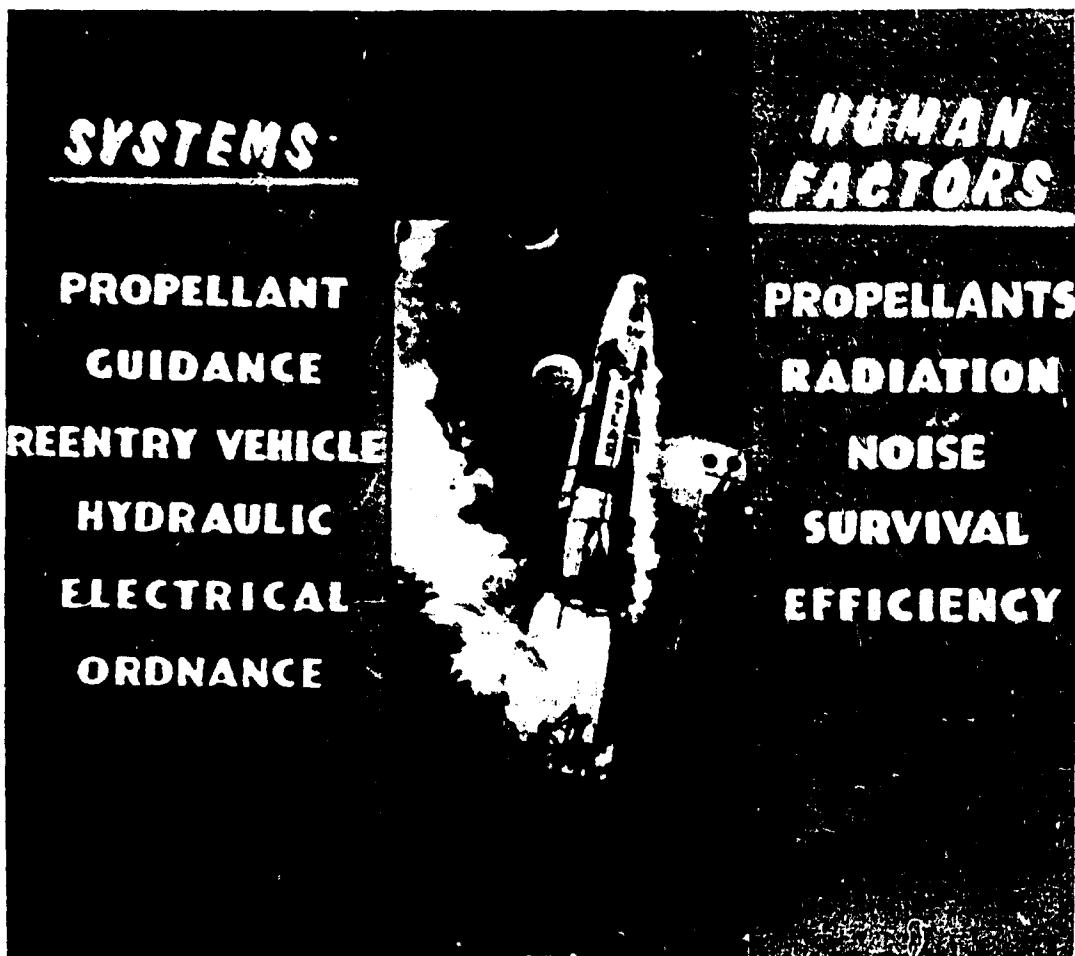


Figure 1

**ORBITAR VEHICLE TOXICITY TESTS**  
**COMMITTEE ON TOXICITY**  
**CONFIDENTIAL - NOT FOR PUBLIC RELEASE**

# Toxicities

fuel	mac	major system affected	symptoms	medical evaluation
LH <sub>2</sub>	-	SKIN	BURNS	N/A
UDMH	0.5	RESPIRATORY	PUL. EDEMA	MONTHLY SCREENING COMPLETE EVERY 6 MOS
HYDRAZINE	1.0	LIVER	JAUNDICE	
AEROZINE	0.5-1.0	CNS SKIN	CONVULSIONS BURNS	
RP-1	-	SKIN CNS	DERMATITIS NARCOSIS	ANNUAL

Figure 2

# Toxicities

oxidizer	mac	major system affected	symptoms	medical evaluation
LOX	-	SKIN	BURNS	N/A
RNA	5*	RESPIRATORY	PUL. EDEMA	6 MOS
N <sub>2</sub> O <sub>4</sub>		HEMOPOIETIC	ANEMIA	

\* MAC BASED ON NO<sub>2</sub>

Figure 3

**Occupational Medicine at the Launch Site** 31  
**Colonel Raymond A. Yerg**



Figure 4

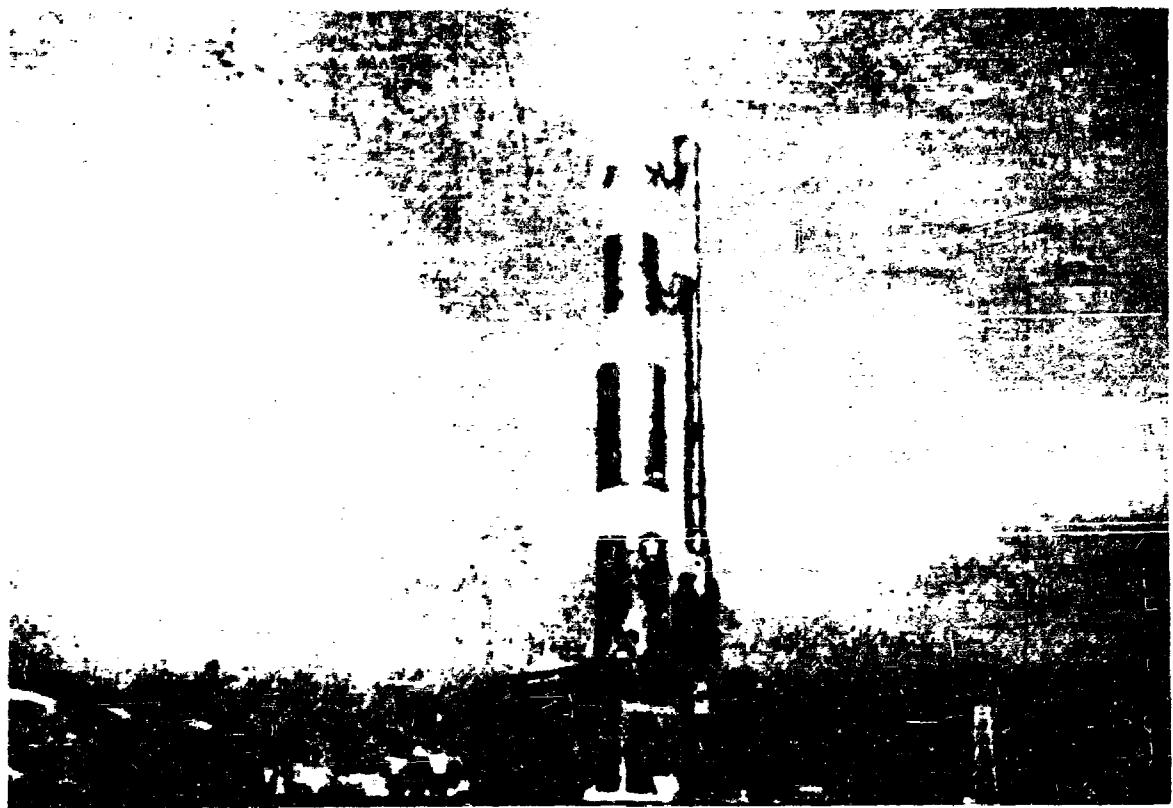


Figure 5

**Occupational Medicine at the Launch Site**  
**Colonel Raymond A. Yerg**



Figure 6

**Occupational Medicine at the Launch Site**  
**Colonel Raymond A. Yerg**

33

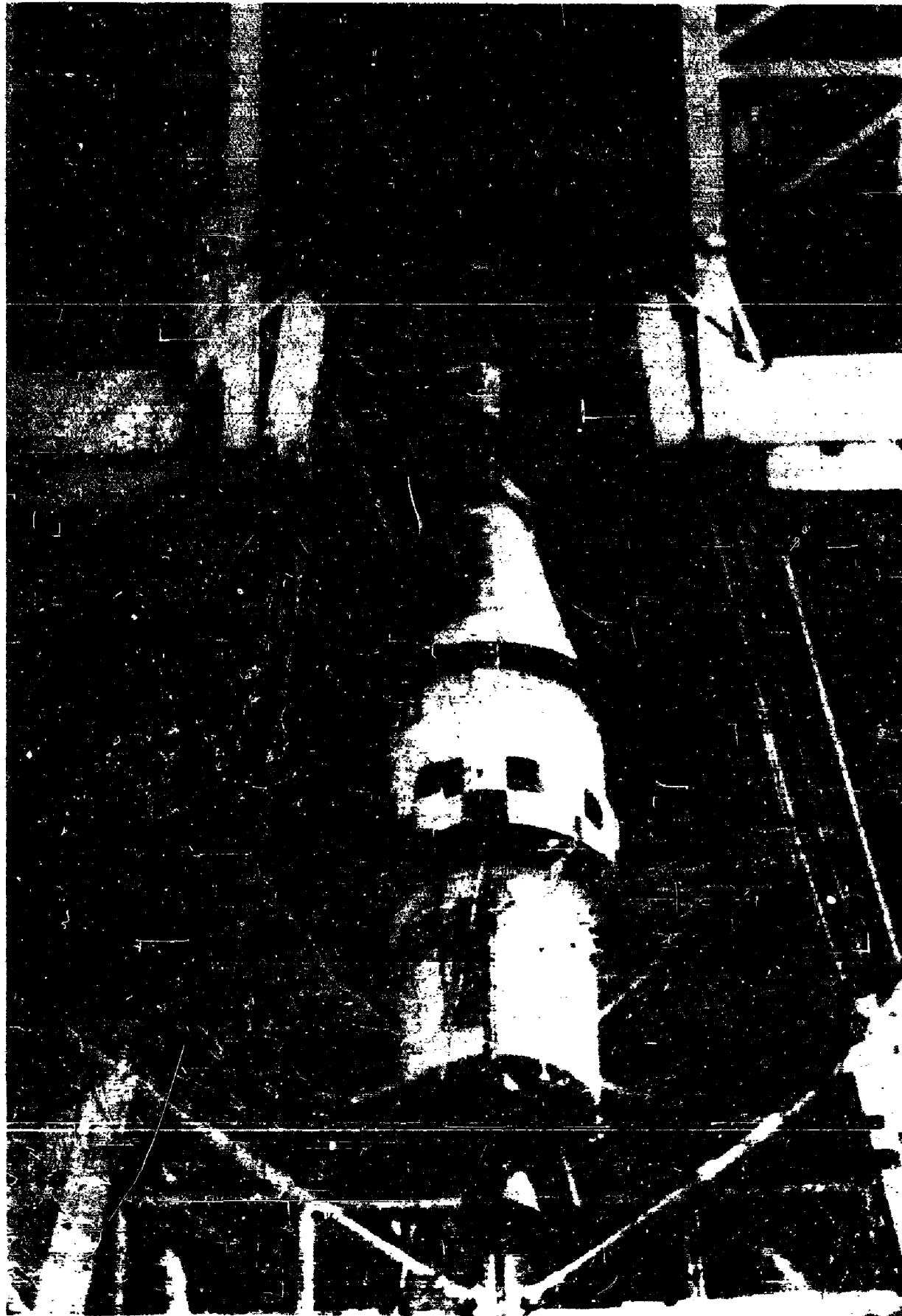


Figure 7

## Occupational Medicine at the Launch Site

### Colonel Raymond A. Yerg

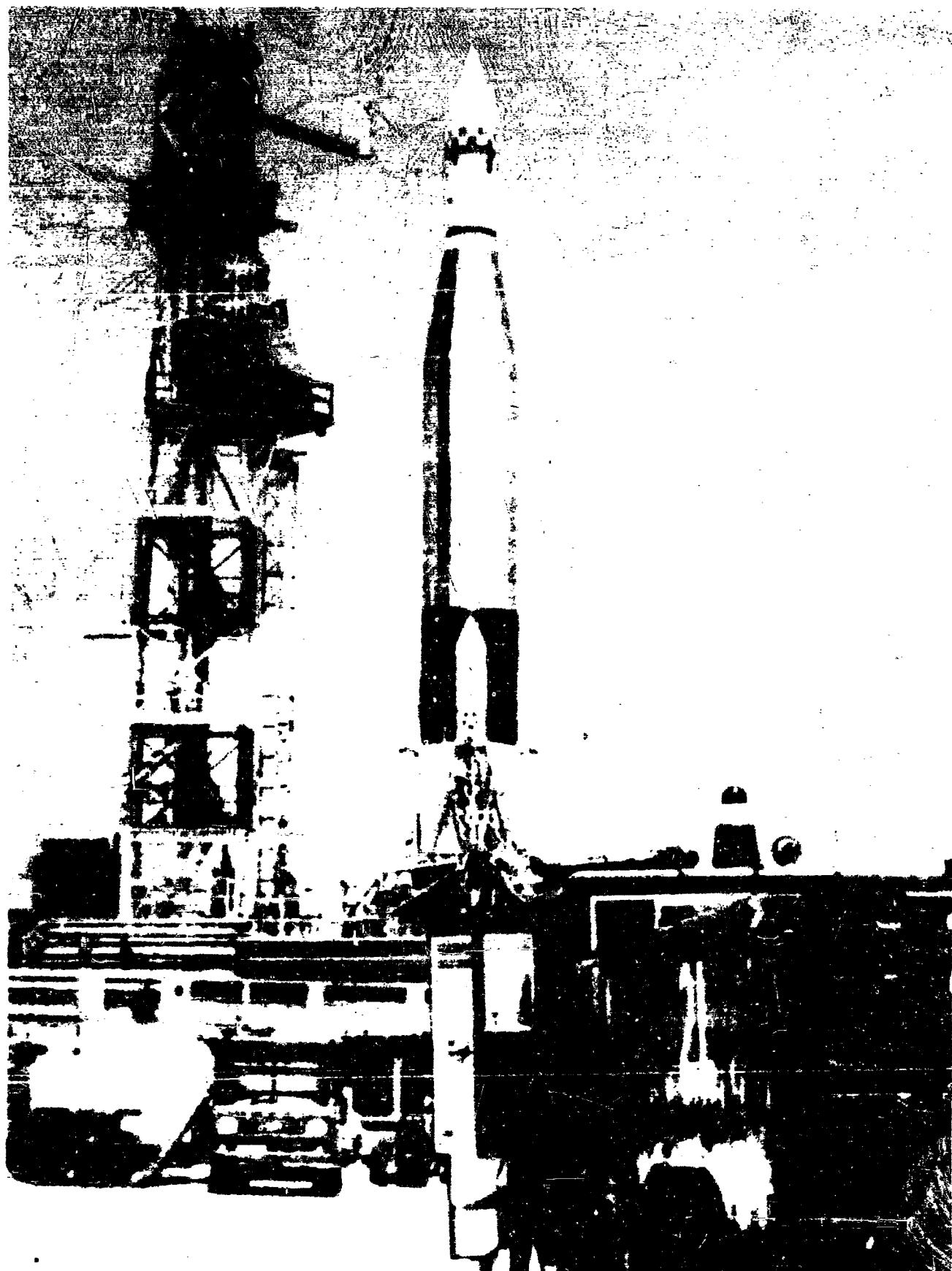
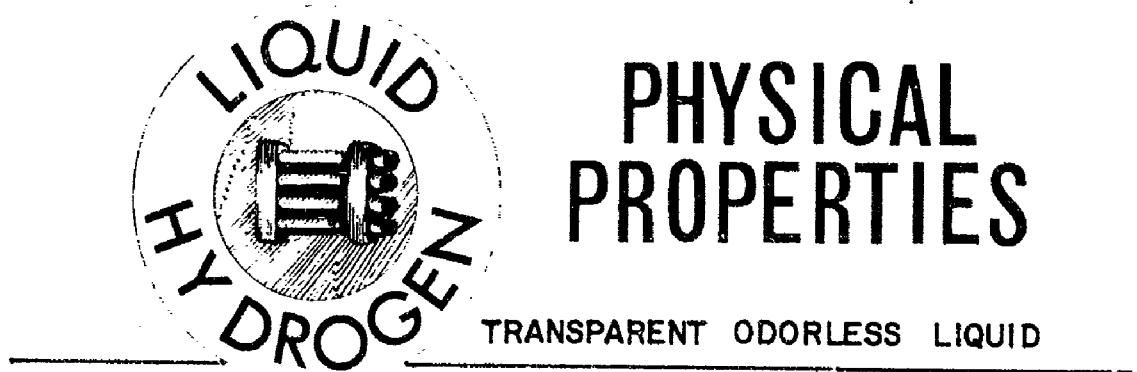


Figure 8



note :

ABSOLUTE ZERO - 459  
BP of He - 452

Figure 9

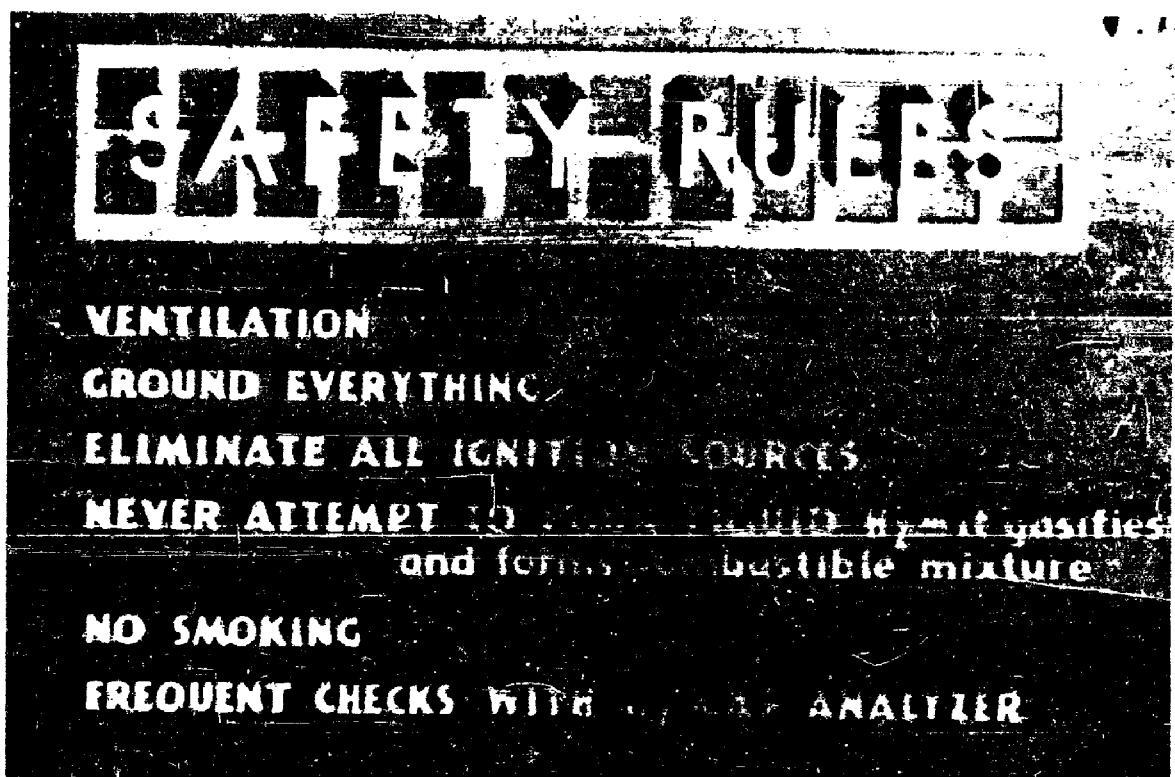


Figure 10

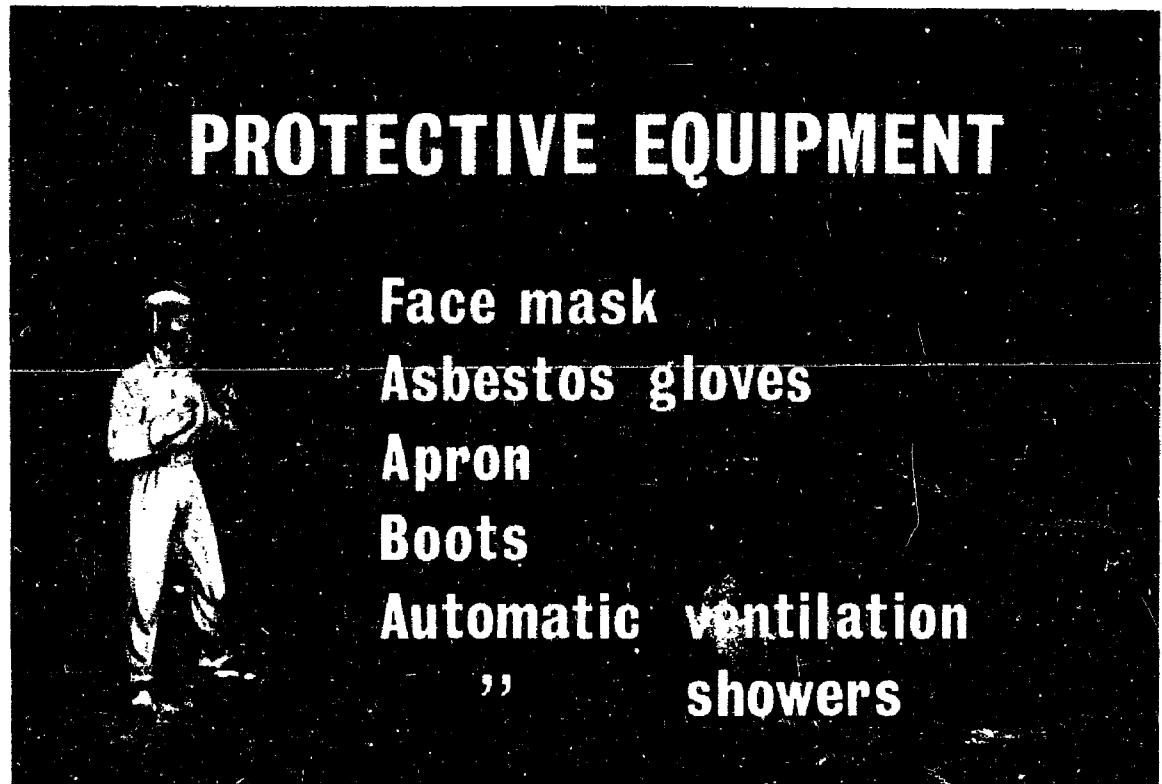


Figure 11

Clustered 1,500,000 lb. thrust  
booster with Titan 2<sup>nd</sup> stage  
and Centaur 3<sup>rd</sup> stage.



Figure 12

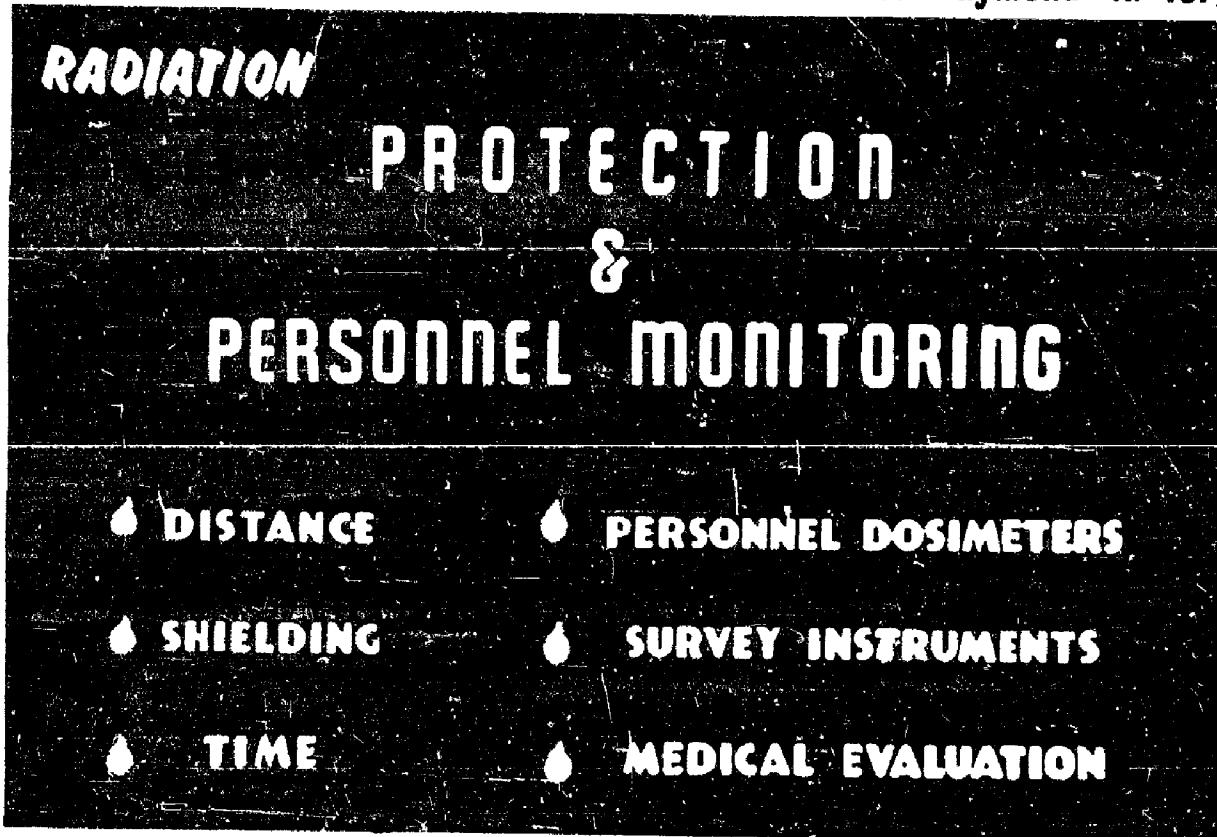


Figure 13

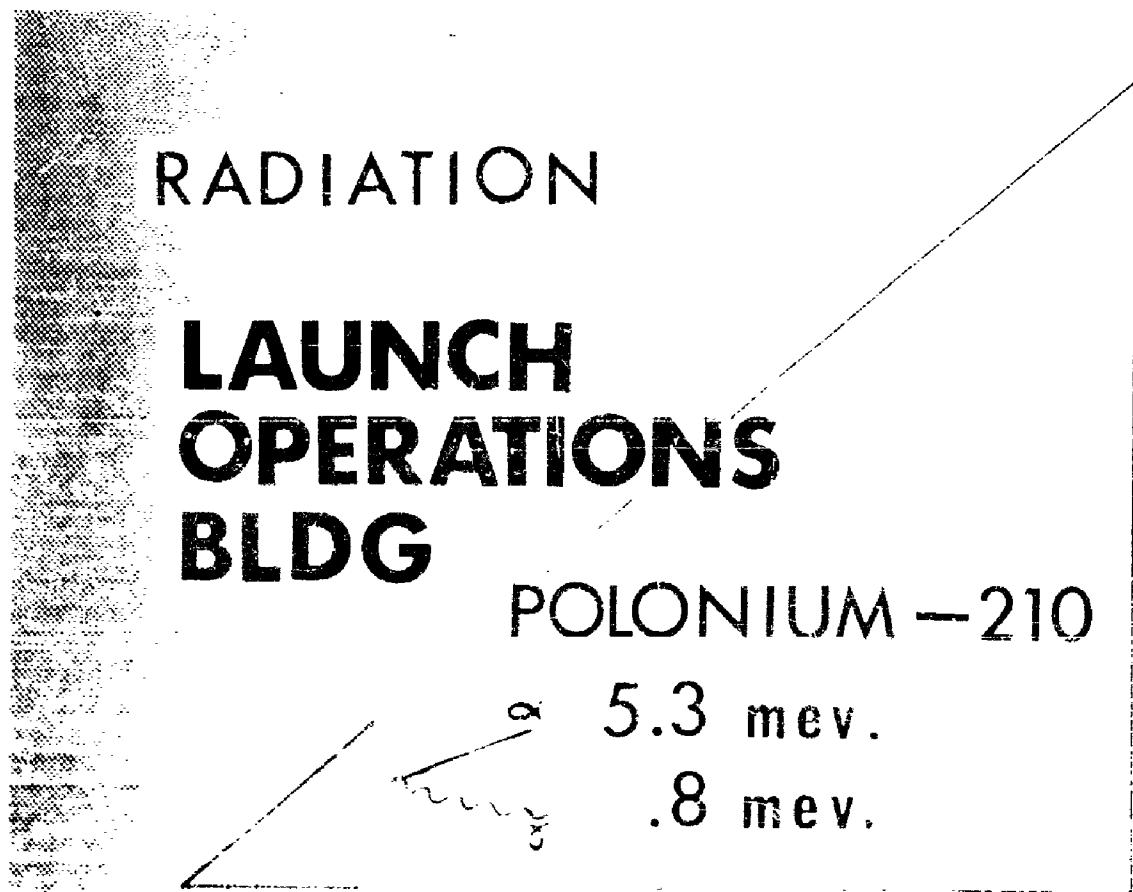


Figure 14

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Colonel Raymond A. Yerg

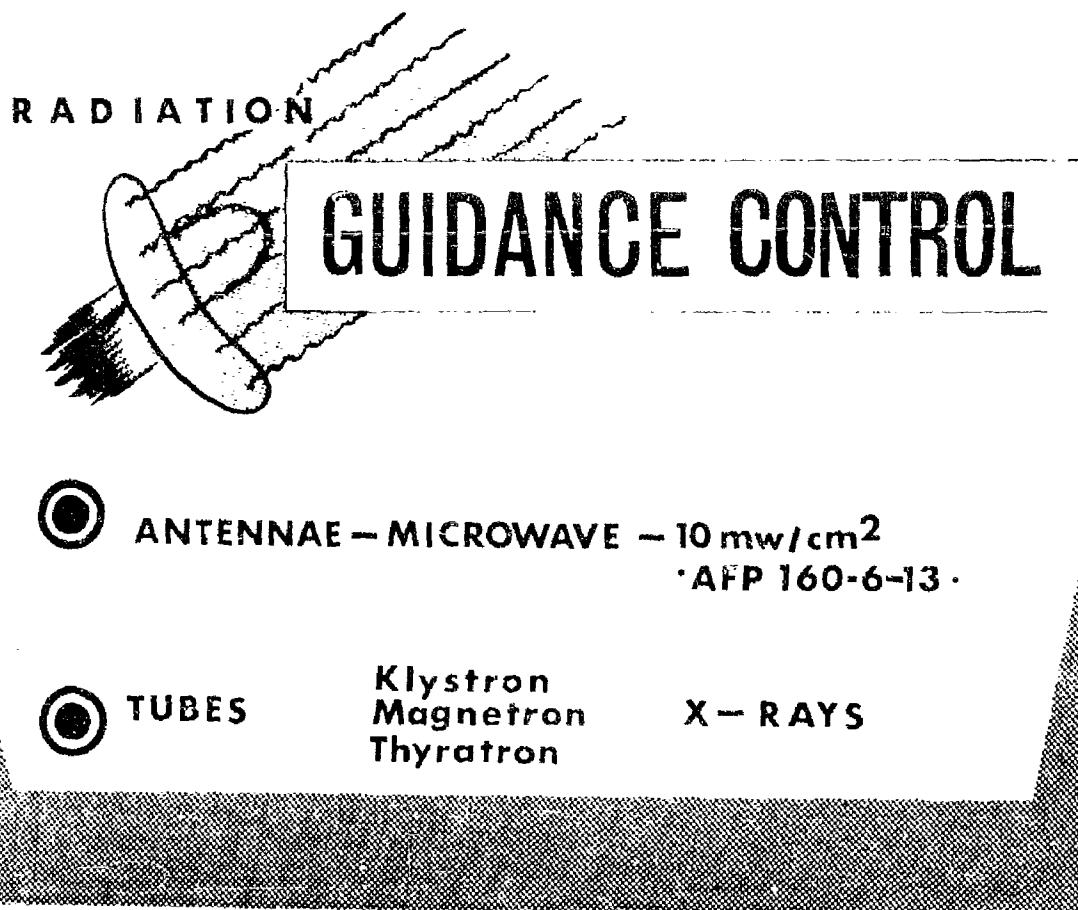


Figure 15

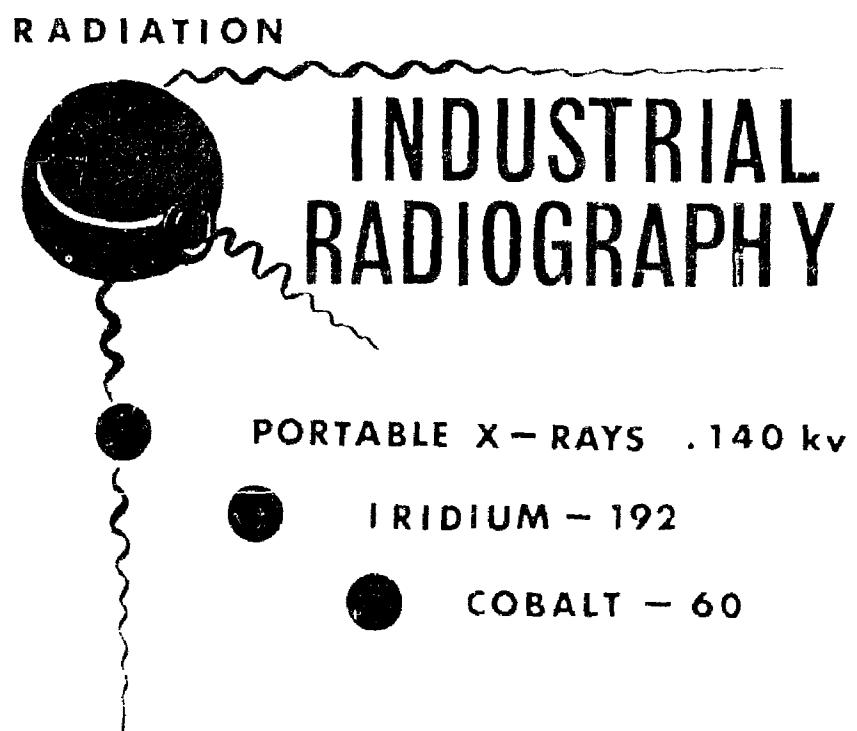


Figure 16

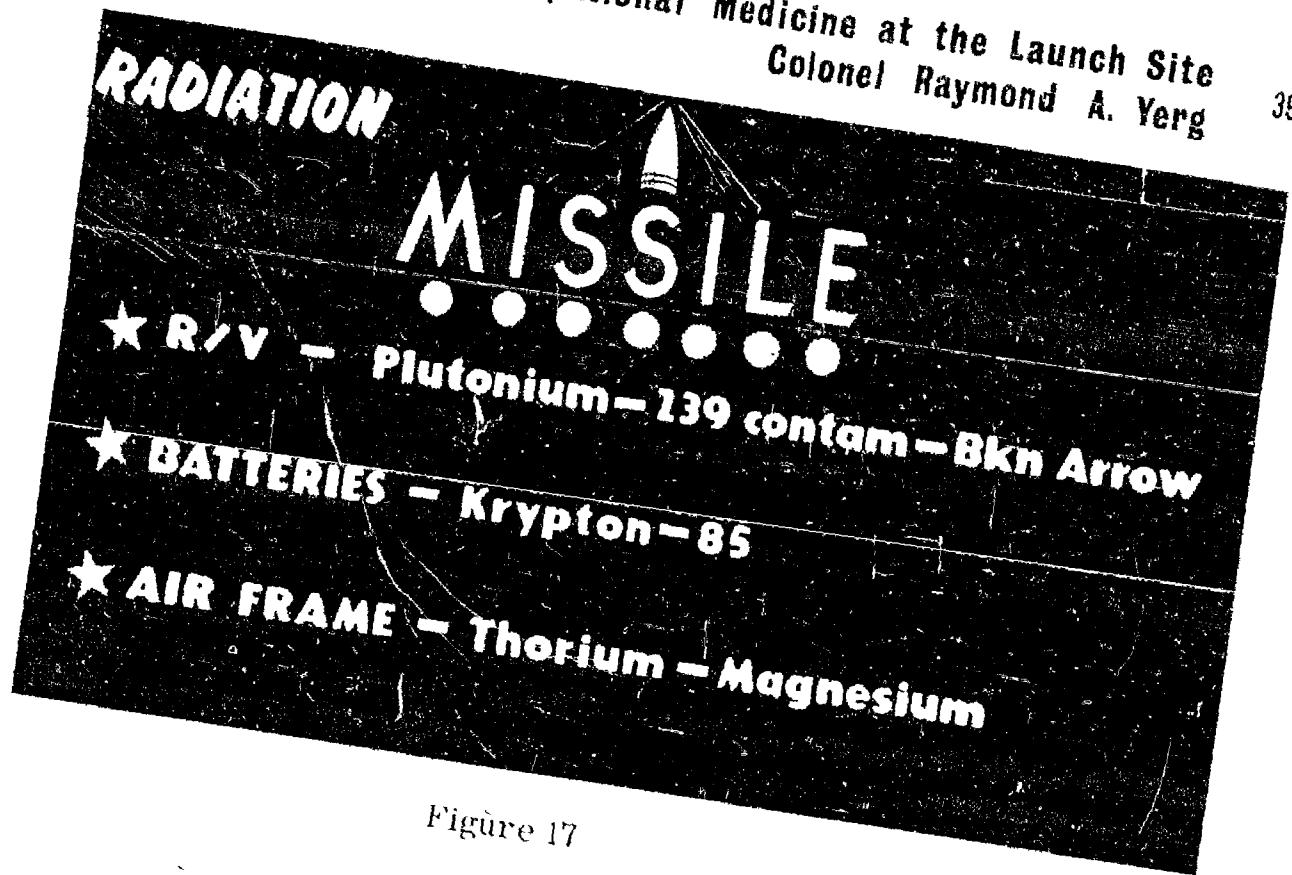


Figure 17

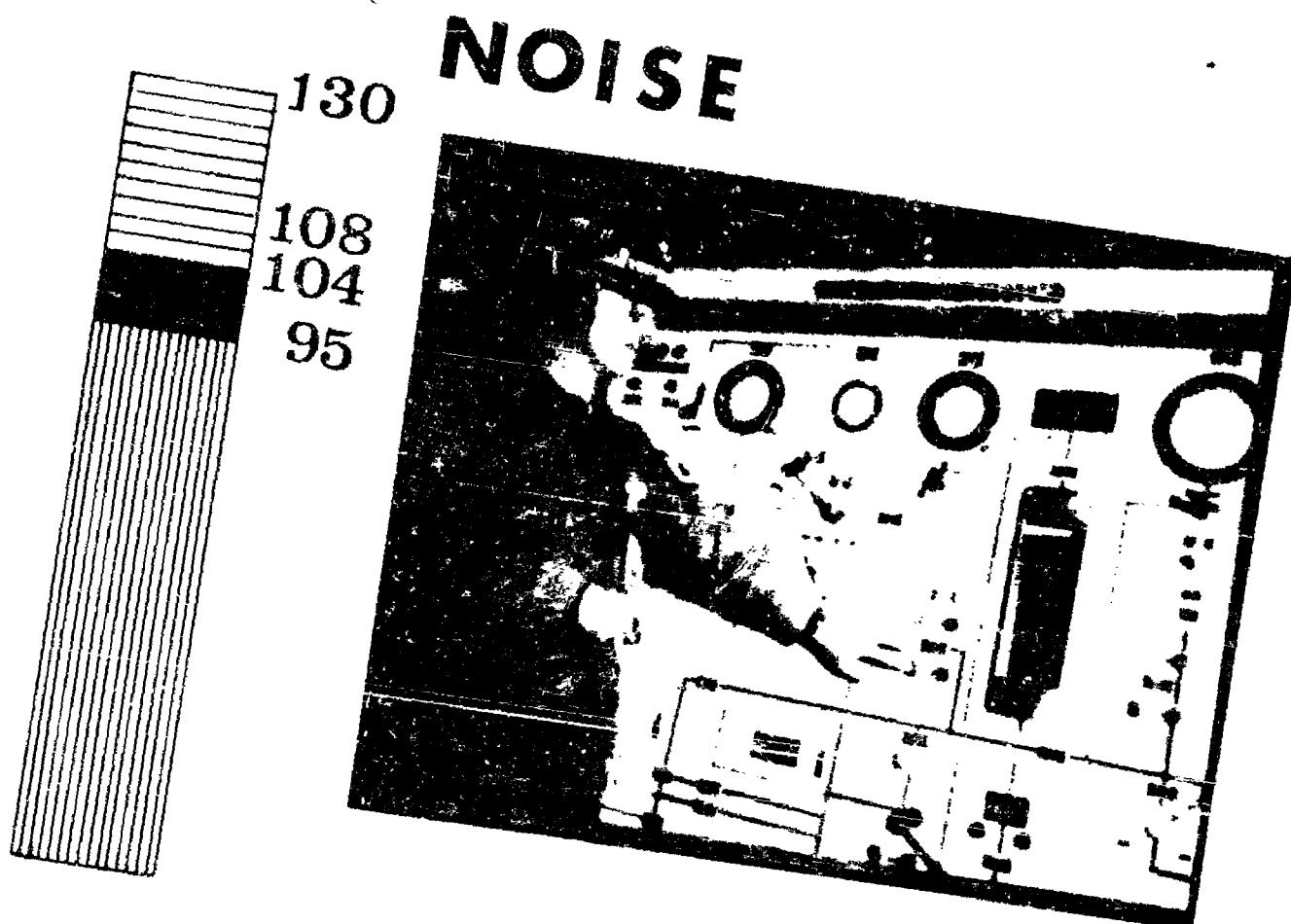


Figure 18

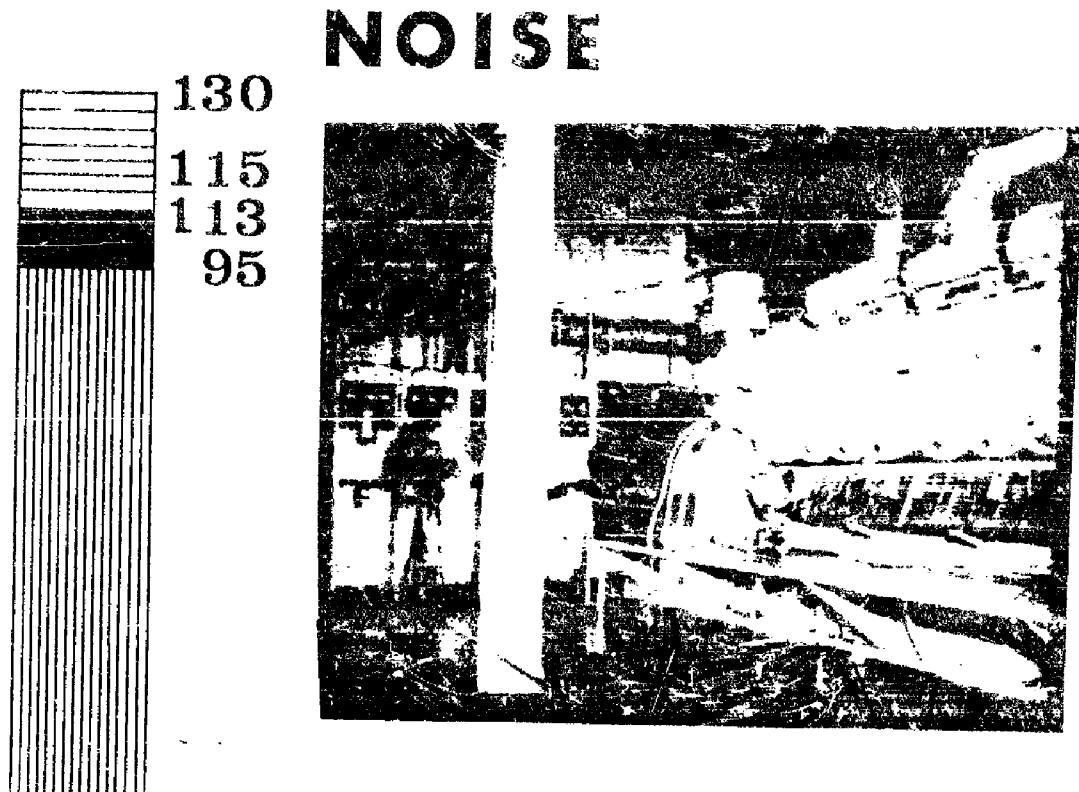
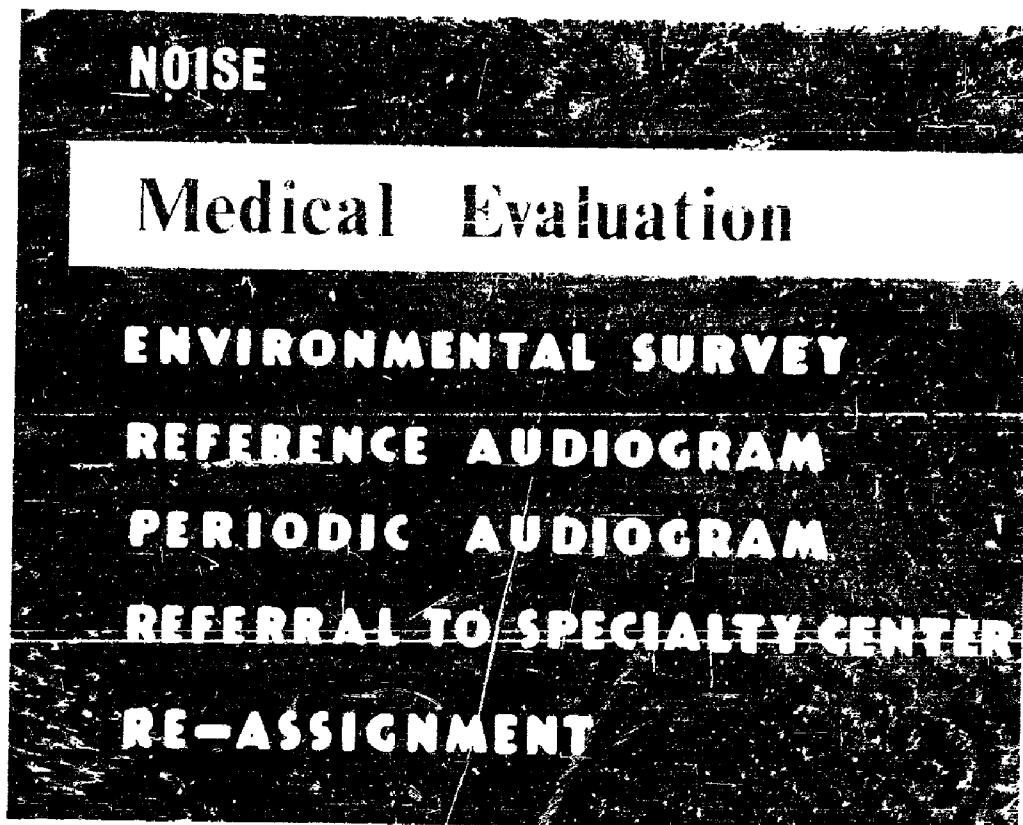


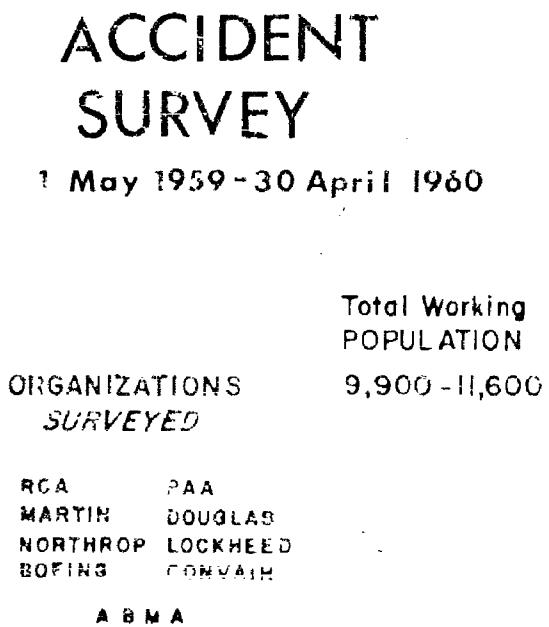
Figure 19



## efficiency & survival **SELECTION FACTORS**

- good physical stamina
- normal color vision
- acceptable visual acuity
- reference audiogram
- emotional & mental stability

Figure 2)



## MISSILE VS INDUSTRIAL ACCIDENTS

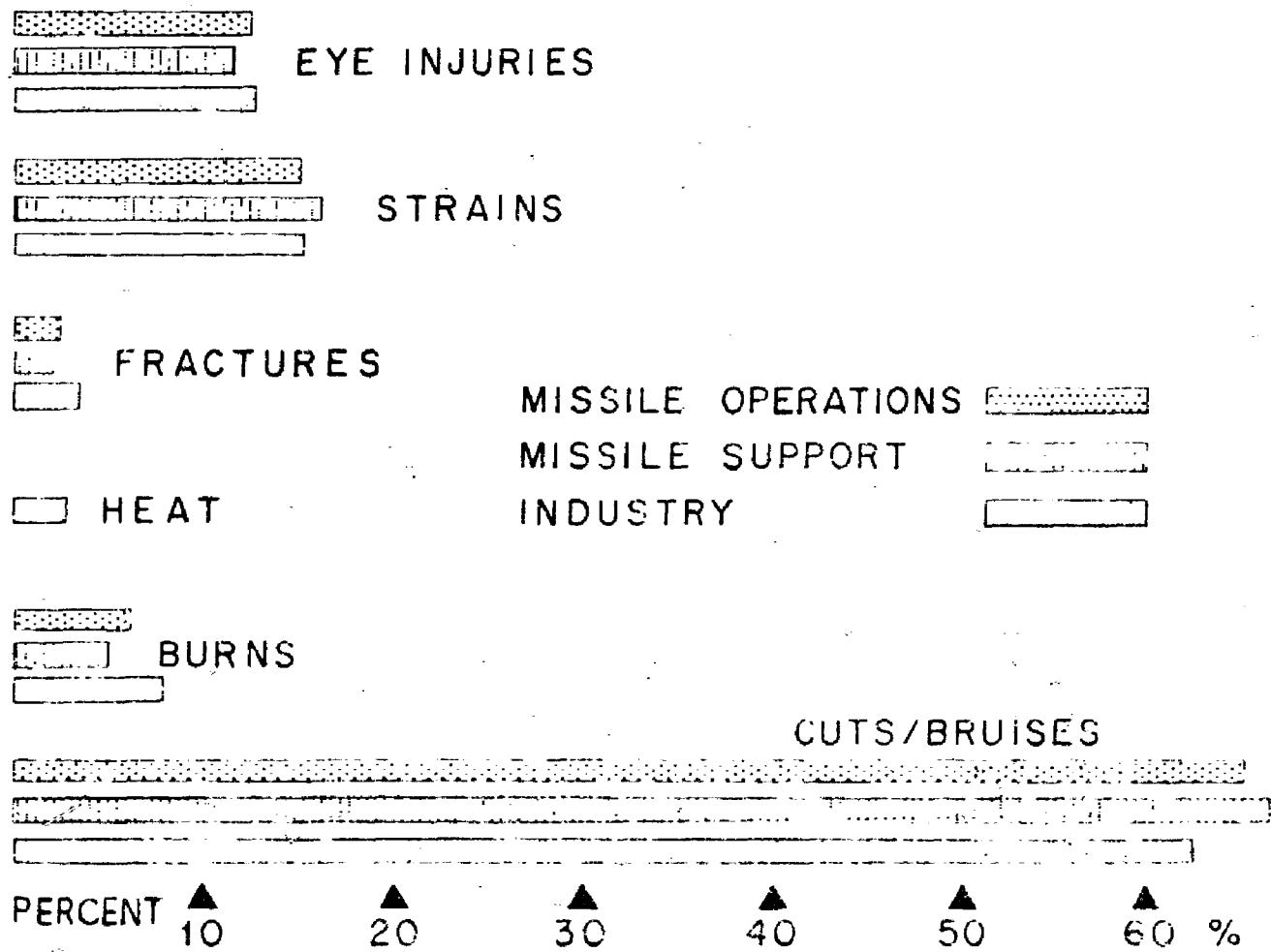


Figure 23

# Accident Type

1 MAY 1959 - 30 APRIL 1960

OPERATIONS ■■■■■ SUPPORT ■■■■■

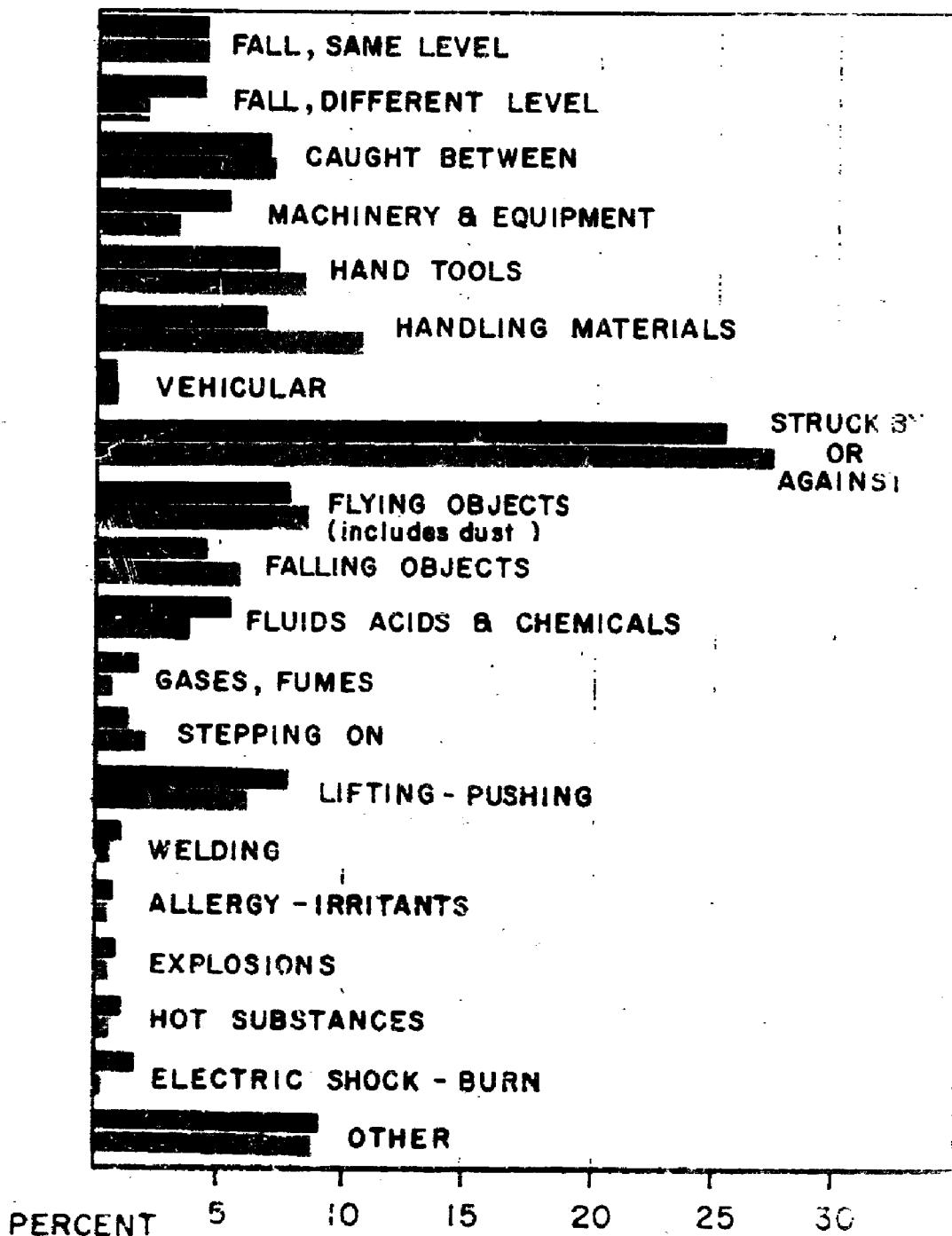


Figure 24

# Occupational Medicine at the Launch Site

## Colonel Raymond A. Yerg

### INJURY TYPE

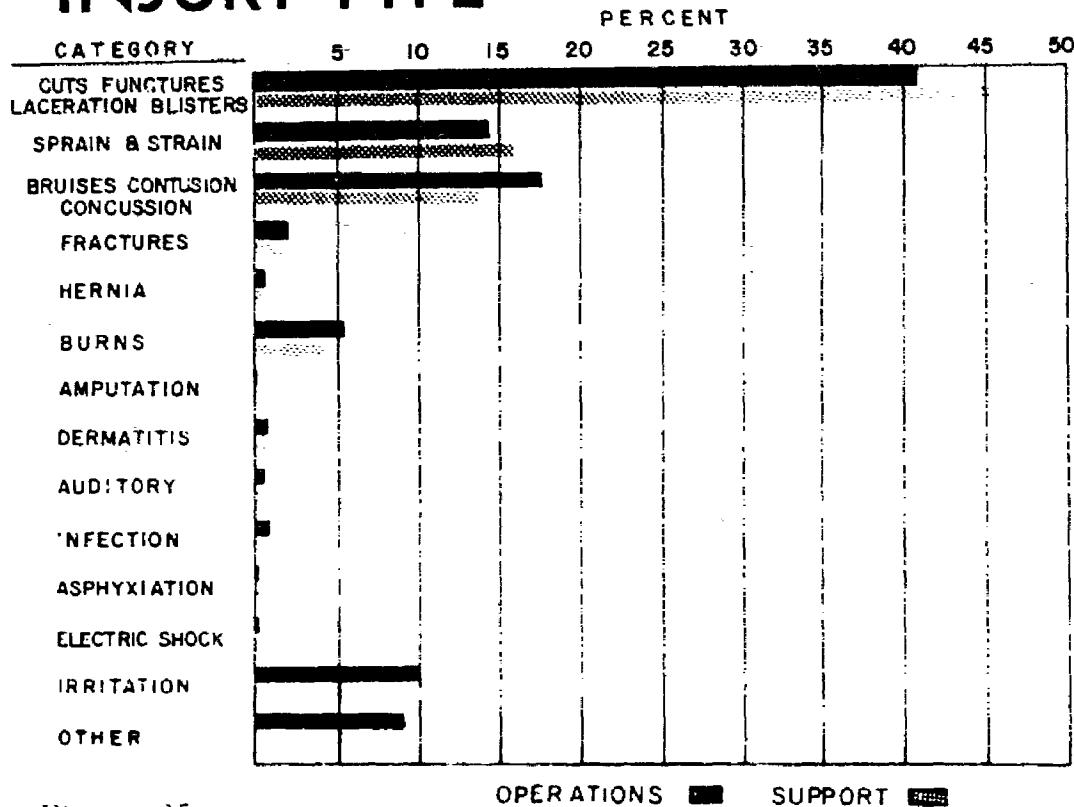


Figure 25

### BODY PARTS INJURED

1 MAY 1959 - 30 APRIL 1960

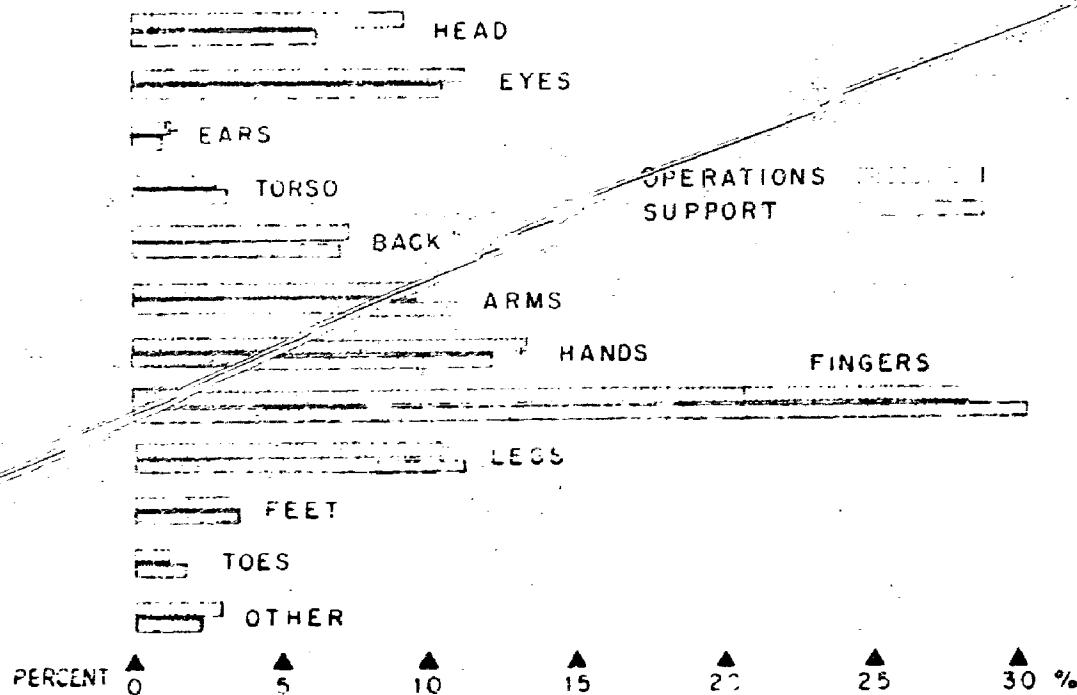


Figure 26

## SELECTION AND STRESS TESTING OF ASTRONAUTS

By

Lawrence E. Lamb, M.D.

Dr. Lamb is Chief of the Department of Internal Medicine and Consultation Services of the School of Aerospace Medicine. His professional education has included graduation from the Medical School of the University of Kansas; Internship, University of Kansas Medical Center; Fellow in Cardiology, Emory University; and Research Fellow, American Heart Association (ECG Research, Geneva, Switzerland). He is certified by the American Board of Internal Medicine. He is a Fellow of the American College of Cardiology and of the American College of Chest Physicians. He received the Dr. Arnold D. Tuttle Award in 1959. He is the sole author of the book Fundamentals of Electrocardiography and Vectorcardiography and numerous professional papers.

Presented at the Lectures in Aerospace Medicine  
Held 8-12 January 1962  
School of Aerospace Medicine

**Selection and Stress Testing of Astronauts**      49  
**Dr. Lawrence E. Lamb**

short periods of time and gradual ambulation. This permits re-education of the anti-g reflexes which provides for normal distribution of blood flow. If an individual exists in a weightless environment for a prolonged period of time, reflex control would deteriorate and loss of circulatory adaptation to changes in g force stimulation would occur. To a lesser extent the same can be said for inhabitation of planets of gravitational fields smaller than that of Planet Earth.

Three practical applications may be immediately deduced from these observations. First, in the event that it becomes necessary to provide space craft with an artificial g environment for travel to a distant planet, it is pointless to increase the artificial gravitational field above the level to be encountered at the target planet. In case of travel to the Moon, which has a gravitational field of one-sixth g force, it would be unnecessary to consider establishing a gravitational field within the vehicle in excess of one-sixth g force. The second point is that the gradual ambulation of clinical patients noted during convalescence, which is in essence a re-education of anti-g reflexes, establishes the point that reflex control of the circulatory system can be obtained through a gradual process of education or training. Improvement of adaptation of circulatory reflexes is feasible. The third application of some importance is that after a person has been exposed to prolonged periods of decreased g force, return to Planet Earth will affect the circulatory system similarly to the way assuming the upright posture affects one after prolonged periods of bed rest. It may be assumed that the circulatory system will be less capable of adapting to changes in the amount of g force applied to it and adverse circulatory responses would more likely be encountered during return to Earth than on departure from Earth.

Increased g force may markedly affect the cardiac rhythm. Various stresses which increase cardiac work initiate a sympathetic acceleration phase of cardiovascular adaptation. During increased g load there is a marked increase in heart rate; with its cessation, marked slowing of the heart may occur. This may be thought of as a vagal rebound period during which vagal activity is dominant. The changes in heart rates before and after stress are indications of the circulatory system's reflex adaptability to stress. We have studied this problem by employing tilt table procedures. Subjects are first placed on the tilt table in the horizontal position. Following this they are subjected to orthostatic stresses followed by maximum breathholding, and hyperventilation followed by maximum breathholding. These relatively minor stresses have frequently shown dramatic disturbances in cardiovascular dynamics both in terms of vasodepressor reactions and cardioinhibitory responses. These responses with the subject feet down usually result in syncopal episodes (Figure 2).

## Selection and Stress Testing of Astronauts

50 Dr. Lawrence E. Lamb

Following the period of stresses in the orthostatic position the subject is tilted head down at an angle of 45 degrees. This change in position represents a change from plus 1 g to minus 0.7 g force. In the head-down position a redistribution of blood occurs. It would be expected that the blood pressure to the brain would be in excess of the blood pressure occurring at heart level. Peripheral signs of increased distribution of blood to the head can be noted by skin color and venous engorgement. As soon as the subject is tilted to the head-down position a precipitous drop in heart rate is often observed. This is usually accompanied by various cardiac arrhythmias including sinus arrest with idioventricular rhythm and short bursts of atrial tachycardia (Figures 3, 4, 5). The most common arrhythmia noted is simple sinus bradycardia with atrial premature contractions. The initial precipitous drop in heart rate is short in duration after which the heart rate is increased but usually remains at a lower rate than observed on the baseline determination before the entire procedure began. As soon as the subject is tilted feet down again there is most often an immediate return to increased heart rate. Although the disturbances in cardiac rhythm associated with relatively small g forces are striking, in no instance have we noted episodes of loss of consciousness induced by such mechanisms. This is just the opposite of the observations made in subjects feet down in whom responses of this magnitude are frequently associated with syncope. This points up the importance of considering the entire picture of the circulatory response and the importance of the amount of blood flow to the brain.

These studies have considerable bearing on the changes in cardiac rhythm which might be expected during space flight. Initially, during the launching phase increased g forces will be applied. This, in combination with other factors, will result in a marked sympathetic acceleration phase with increased heart rate. Once orbital velocity is reached, weightlessness will occur and g stress will cease. At this point relative cardiac slowing should be expected. The stage is set for the vagotonic rebound phase. In evaluating rhythms noted during weightlessness, one should take cognizance of the point that rather striking arrhythmias may not be of major significance if cerebral blood flow is maintained. It seems reasonable to assume that individuals whose circulatory system can readily adapt to changing stresses without marked changes in cardiac rhythm would have better circulatory reflex adaptability during space flight.

During cardioinhibitory responses, if an active ectopic pacemaker is present in the heart, ectopic arrhythmias may occur. During transitory sinus arrest after an episode of atrial tachycardia, frequent bursts of ventricular tachycardia are not uncommon. It would seem reasonable that individuals who have an active ectopic

## **Selection and Stress Testing of Astronauts**

**Dr. Lawrence E. Lamb**

51

pacemaker would be more likely to develop a significant ectopic arrhythmia in space flight in the presence of a cardioinhibitory response.

A number of arrhythmias noted during stress-testing in normal subjects do not induce adverse reactions. By combinations of stress-testing with the tilt table and breathing maneuvers we have frequently noted intermittent A-V dissociation and change of the primary pacemaker from the sinus node to an atrial location. These minor changes in cardiac rhythm may occur without significant alteration in cardiovascular dynamics. They occur commonly in the absence of any significant underlying heart disease. Failure to recognize this point can easily result in overemphasis of the significance of such a finding while monitoring a space flight and result in abortion of an otherwise successful venture.

The electrocardiogram is a useful tool in monitoring individuals during stress studies and will be utilized as a monitoring tool during space flights. This requires a critical analysis of the type of information which may be gained with electrocardiographic monitoring. It is infallible in demonstrating changes in cardiac rate and changes in cardiac rhythm. However, not all cardiac arrhythmias have an ominous significance and many are, in fact, inconsequential when the total picture of circulatory dynamics is considered. In addition to detecting changes in cardiac rhythm, the electrocardiogram is used clinically to determine myocardial ischemia and changes in myocardial function. Care should be taken in making such interpretations, however, because changes in the electrocardiogram of normal subjects often mimic the changes characteristic of myocardial ischemia. The most common error is overemphasis of the importance of changes in ST segments and T waves in individuals exposed to various forms of stress. T wave changes are not analogous to myocardial ischemia, myocardial injury, or a host of other ominous-sounding terms. It has been repeatedly demonstrated that T wave changes are frequently encountered with such simple procedures as standing up. They may also be induced by various respiratory maneuvers, including breathholding and hyperventilation (Figure 6). This makes it nearly impossible to assume that ST segment and T wave changes noted during the stresses of space flight can be used as a reliable index of myocardial insufficiency.

Certain types of lead systems can be utilized to detect changes in cardiac position. The heart may be markedly displaced by increasing force. Such changes in cardiac position can readily be detected by three mutually perpendicular leads or a method of measuring displacement of the heart from left-to-right, up-and-down and anterior-posterior directions. This is not always feasible if only one electrocardiographic lead is utilized. In summary, the electrocardiogram

## Selection and Stress Testing of Astronauts

Dr. Lawrence E. Lamb

can be used in monitoring procedures for detection of cardiac arrhythmias and changes in cardiac rate, with certain methods to detect changes in cardiac position, but not with any degree of reliability to determine the presence of coronary insufficiency.

Study of individuals during stress procedures requires specialized techniques. To obtain records which are relatively free from artifact, we utilize a screen wire electrode encased in a rubber ring. The rubber ring is filled with electrode paste and the wire screen does not contact the skin (Figure 7). Using electronic filters to eliminate signals with a frequency of greater than 50 cycles per second diminishes artifacts caused by skeletal muscle activity since the latter are more often high frequency events. The quality of the records can be appreciably improved by exercising care in choice of electrode sites. The most stable location is the upper portion of the sternum for one electrode and the lower portion of the sternum for another. There is relatively little underlying skeletal muscle at these sites. A high degree of reliability can be achieved with such a lead using specialized electrodes. Use of an electrode over the sternum and another directly over the vertebral column of the back is reasonably satisfactory (Figure 9). Another choice for lead sites is to place one electrode on the head, on either the forehead or the ear, and another electrode over the bony prominence of the sacrum. Another lead may be formed by placing one electrode in the left midaxillary region (Figure 10). This lead is less stable than the previously mentioned ones, particularly if the individual is engaged in walking activity such as observed during treadmill exertion. When subjects are relatively immobile--in the recumbent position or not swinging the arms--such a lead is more satisfactory.

Within the laboratory, better records may be obtained by using telemetry methods. We have utilized miniature transmitters seated on a helmet (Figure 11). These are connected to the electrodes placed at various locations on the body. The signals are transmitted to a nearby antenna and passed through electronic filters (Figure 12). These, in turn, may be recorded on magnetic tape, ordinary strip recorders, or transmitted directly to oscilloscope recording for visual observation.

Biological data can be easily transmitted utilizing telemetry methods. Once it is received at ground level it may be transmitted either by radio or telephone communications. We have demonstrated that, during stress-testing, we can send signals by telemetry to our recorders and also to an ordinary telephone (Figure 13). The information picked up by the mouthpiece of the ordinary telephone may then

**Dr. Lawrence E. Lamb**

be relayed to a distant location and recorded there. The records obtained prior to transmission by telephone and after transmission by telephone are identical. A similar mechanism can be used with ordinary radio type transmission. This means that it is entirely possible to monitor the cardiovascular system during orbital space flight in a more or less continuous manner, utilizing a communications system that forwards all biological data to a central location.

To summarize, this presentation has extended the application of g forces to special considerations which are expected to be encountered in space flight and space habitation. I have further attempted to demonstrate a laboratory approach to studying the adaptability of circulatory reflexes to types of stresses similar to those which can be expected during aerospace flight. The important implications of reflex control in relationship to g force has been emphasized, particularly in reference to prolonged weightless states or habitation on other planets. The necessity of evaluating cardiac arrhythmias in relationship to blood volume distribution has been pointed up to indicate that relatively striking arrhythmias are not necessarily harmful. It has been suggested that one should be cautious in overinterpreting the significance of ST segment and T wave changes encountered during stressful circumstances as opposed to ST segment and T wave changes incurred in the usual clinical environment. Methods of studying individuals during stress studies utilizing specialized equipment have been indicated and brief comments have been made concerning the utilization of central communications method of transmitting biological data which can be obtained during aerospace flight and during stress-testing.

**Selection and Stress Testing of Astronauts**  
**Dr. Lawrence E. Lamb**

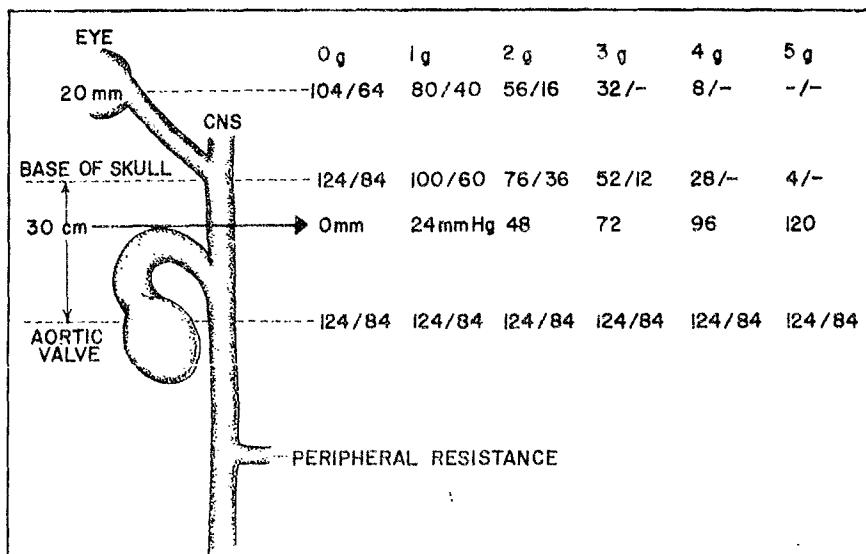


Figure 1 A diagram to illustrate the influence of g force on blood pressure to the brain and eye. See text.

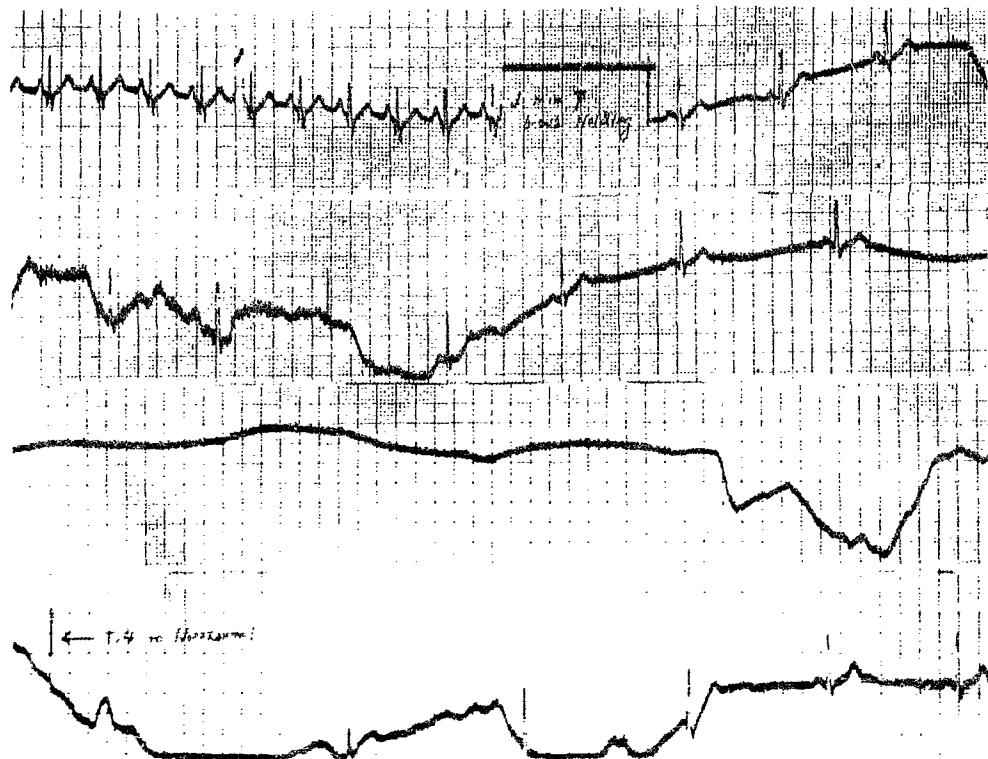


Figure 2 A cardioinertial tracing showing spectral recruitment in syncope with the subject reclining on a turntable.

Figure 3 Sinus tachycardia, rate 120 per minute, changes to sinus bradycardia, rate 35 per minute, after a head-down tilt.

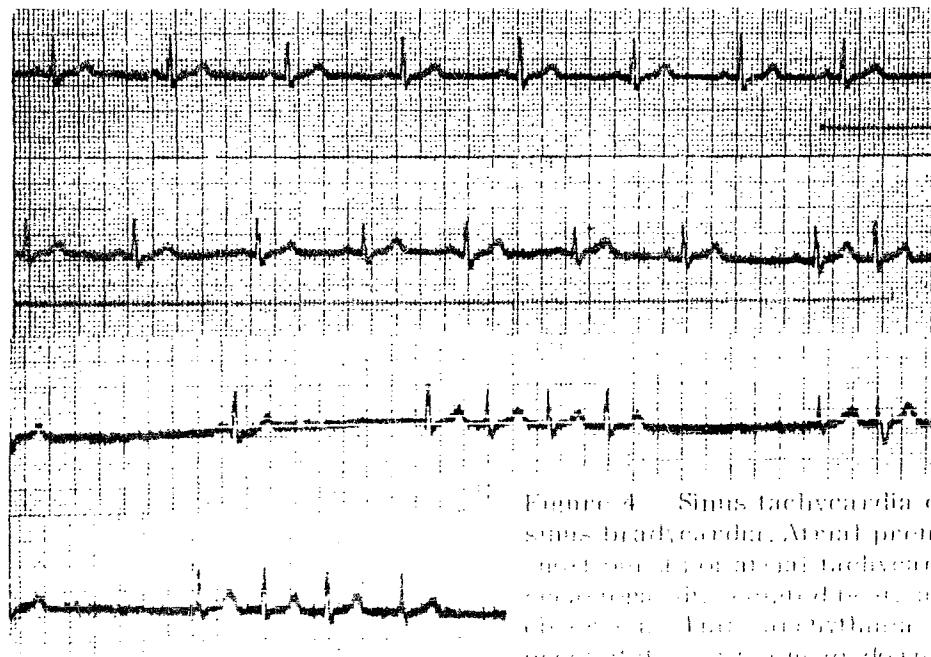
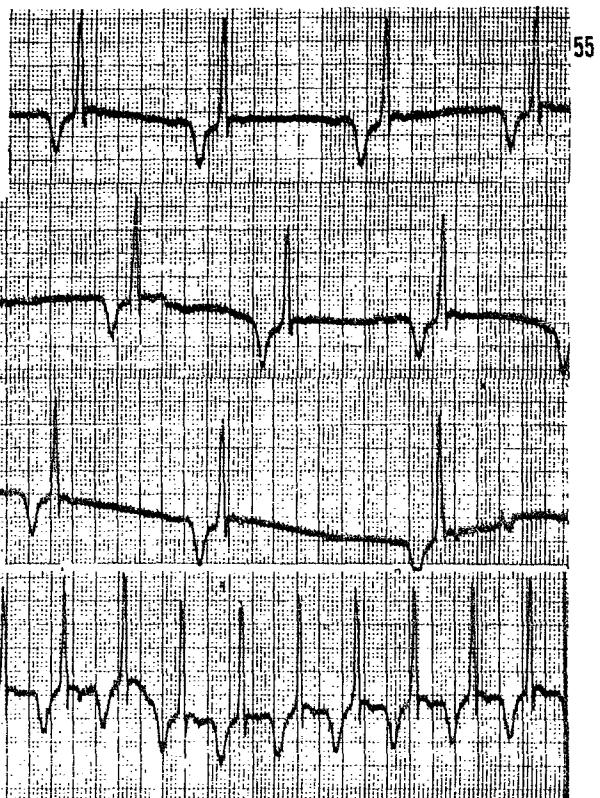


Figure 4 Sinus tachycardia changes to sinus bradycardia. Atrial fibrillation, most likely polymorphic tachycardia and sinus bradycardia developed to sinus bradycardia. Tilt test (orthostatic) with pre-tilt, during tilt, and after tilt.

56 Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb



Figure 1. Heart rate variability following a maximal cardioinhibitory response after exercise in a patient.

Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb

57

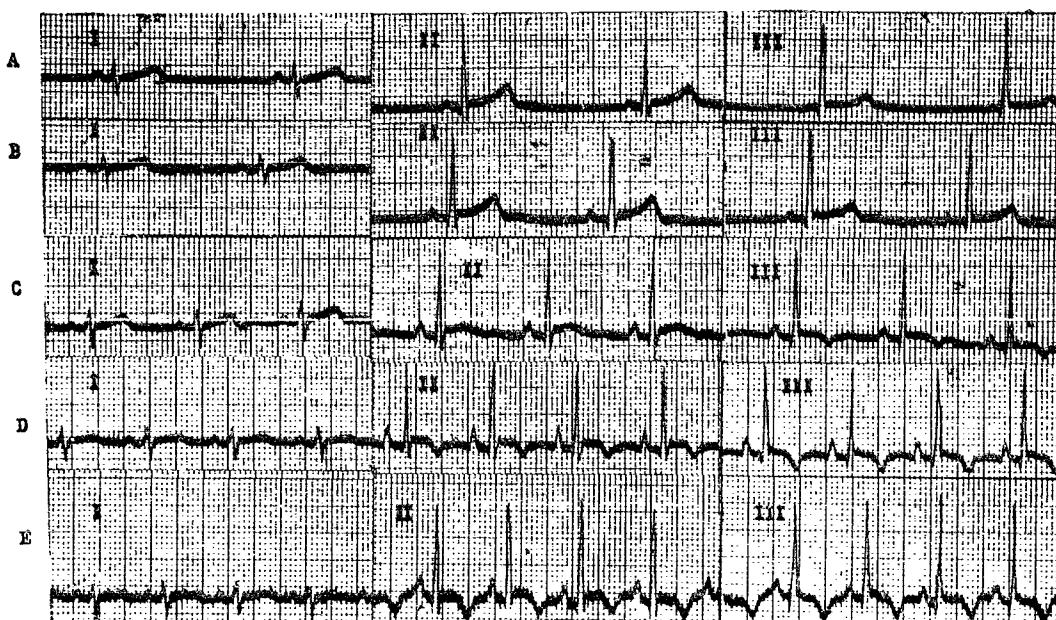


Figure 6 Twenty-year-old aviation cadet. (A) Recumbent. (B) Breathholding recumbent. (C) Tilted feet down on tilt table. (D) Breathholding while tilted feet down. (E) Hyperventilation during tilt.

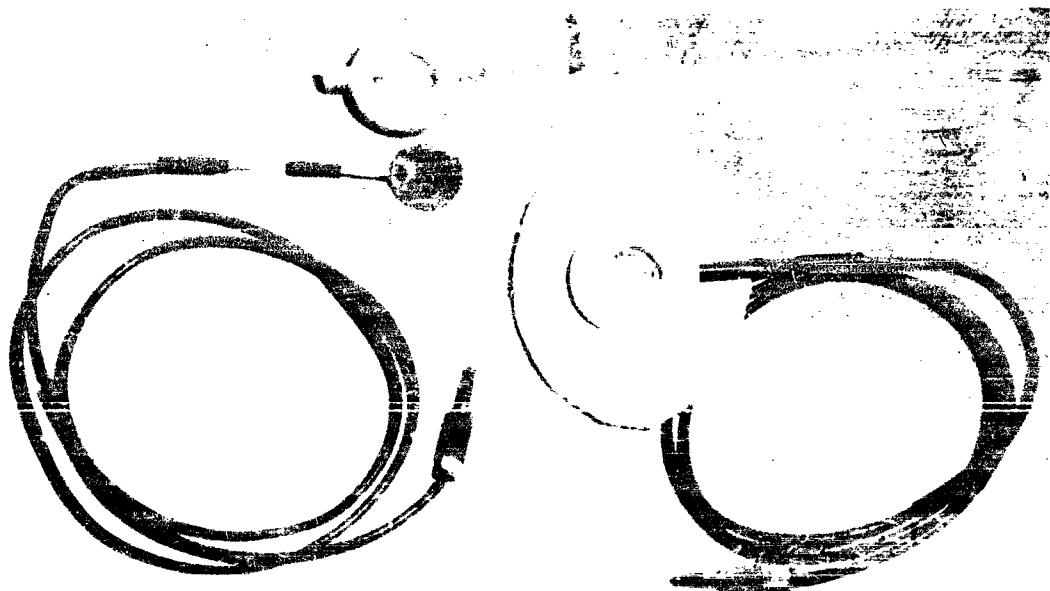


Figure 7 Spacelab electrophysiologist during stress testing.

**Selection and Stress Testing of Astronauts**  
**Dr. Lawrence E. Lamb**

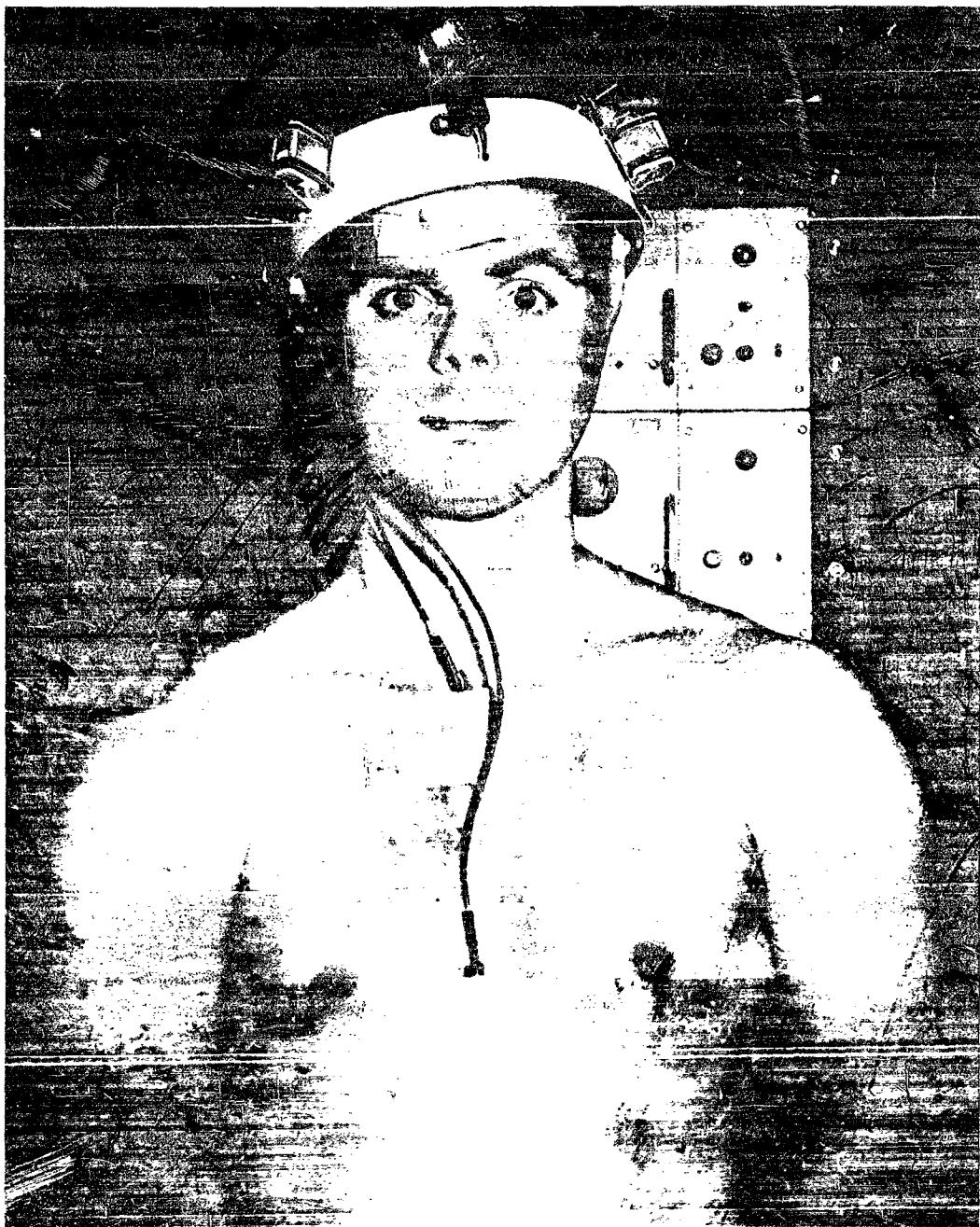


Figure 5 - The sternal lead.

Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb

59



Figure 1. A subject during a preflight test.

60 Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb

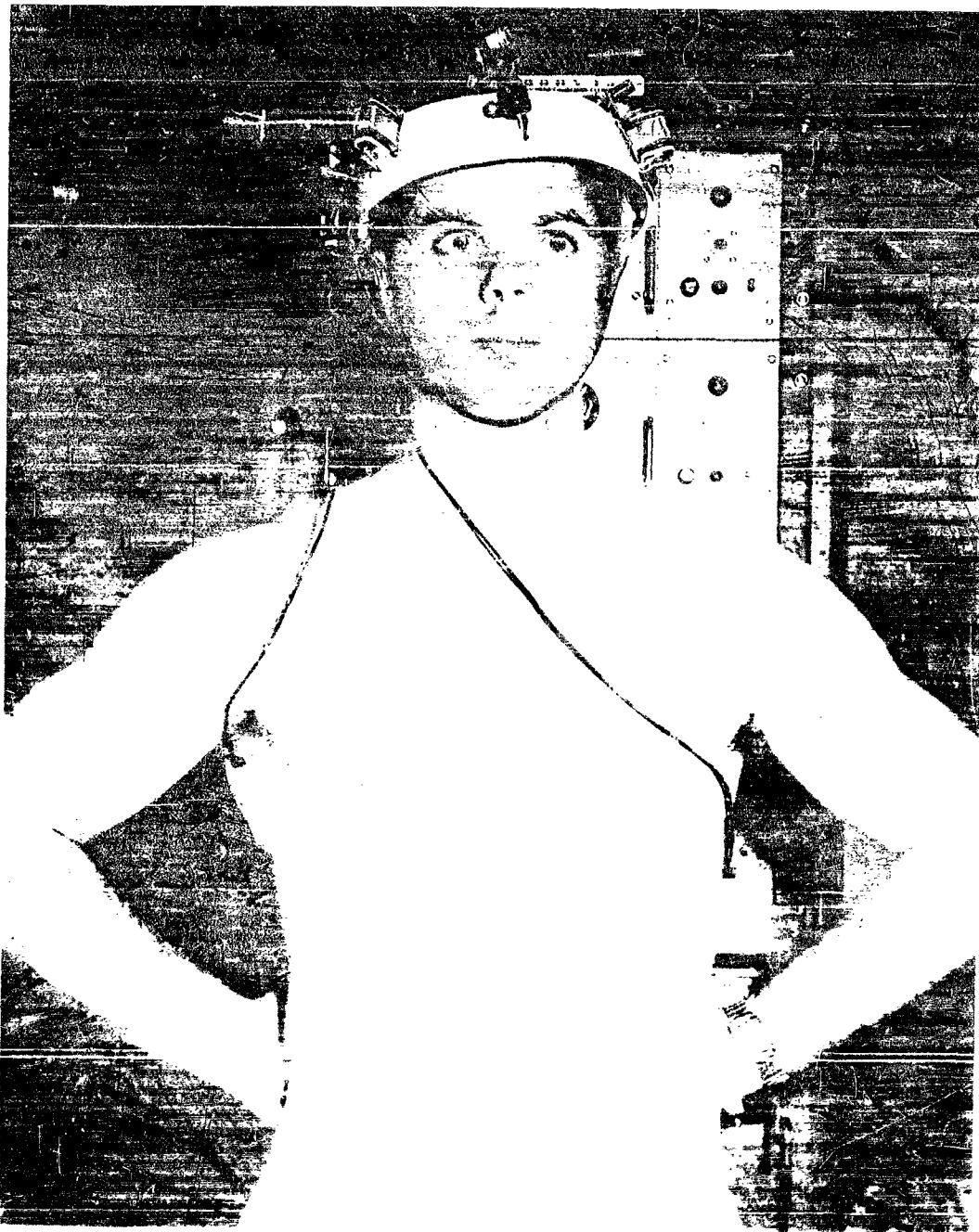


Figure 10 - Pre-flight training flight.

Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb

61

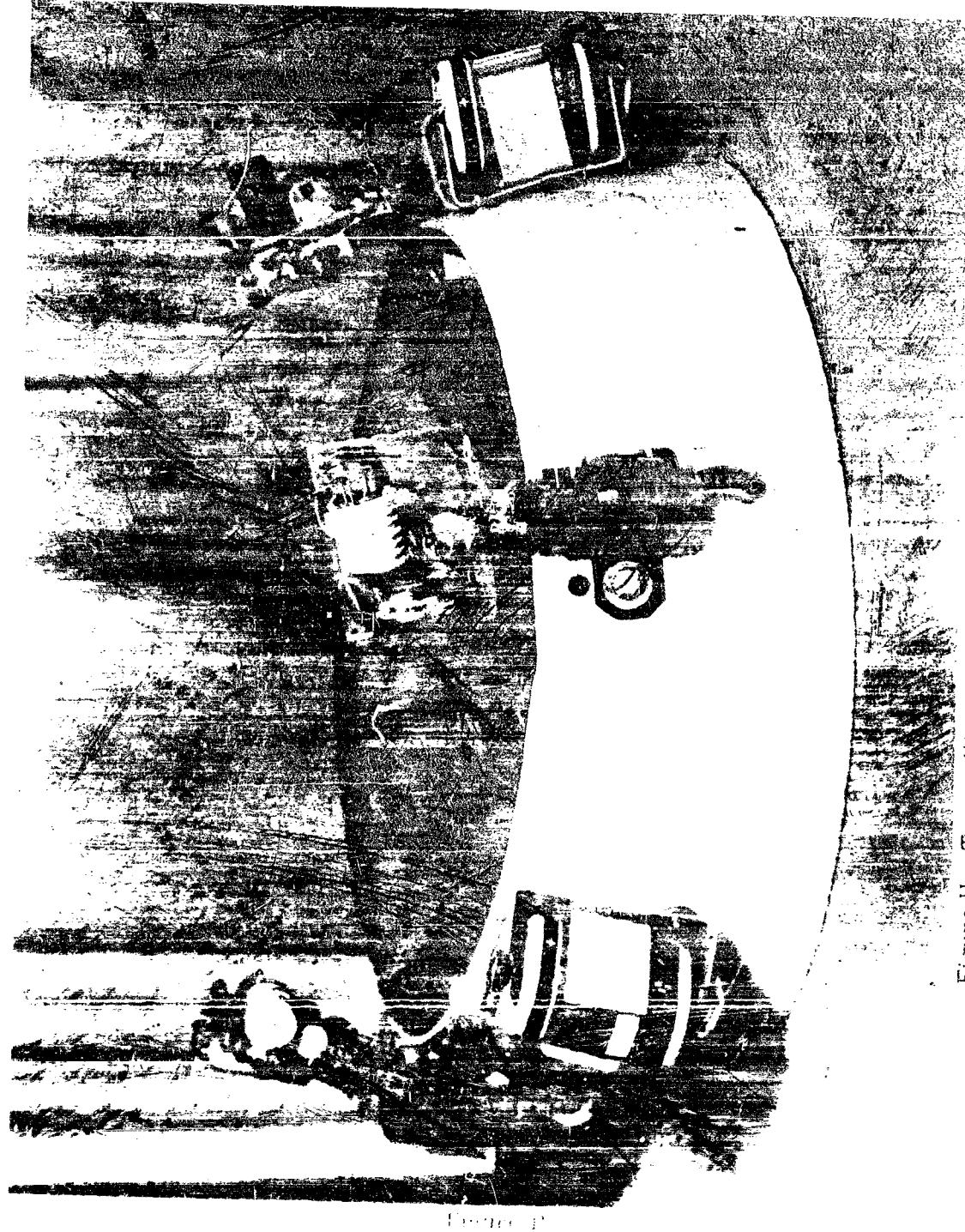
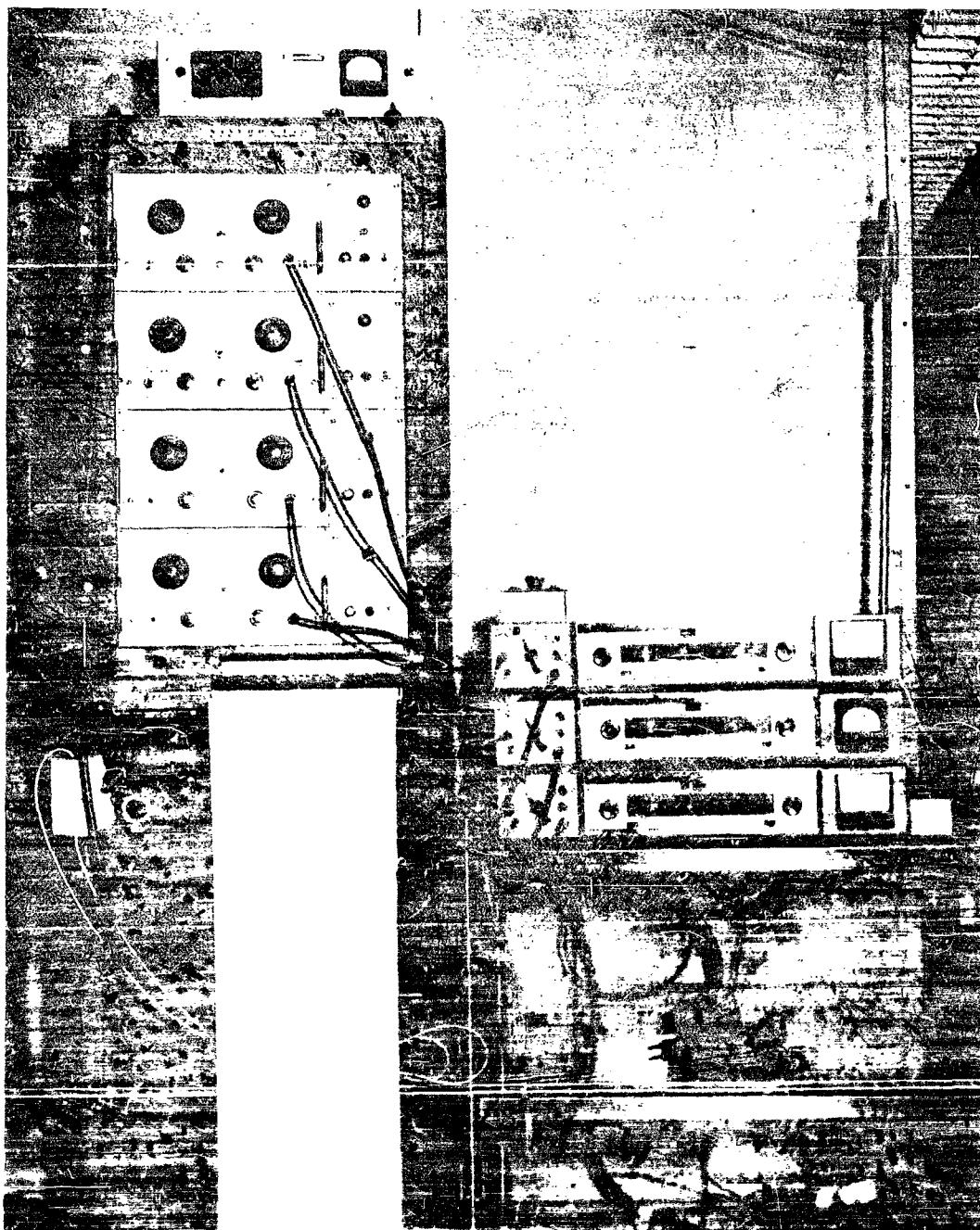


Figure 11 Transmitters for ECG signals mounted on a helmet.

62 Selection and Stress Testing of Astronauts  
Dr. Lawrence E. Lamb



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Selection and Stress Testing of Astronauts 63  
Dr. Lawrence E. Lamb

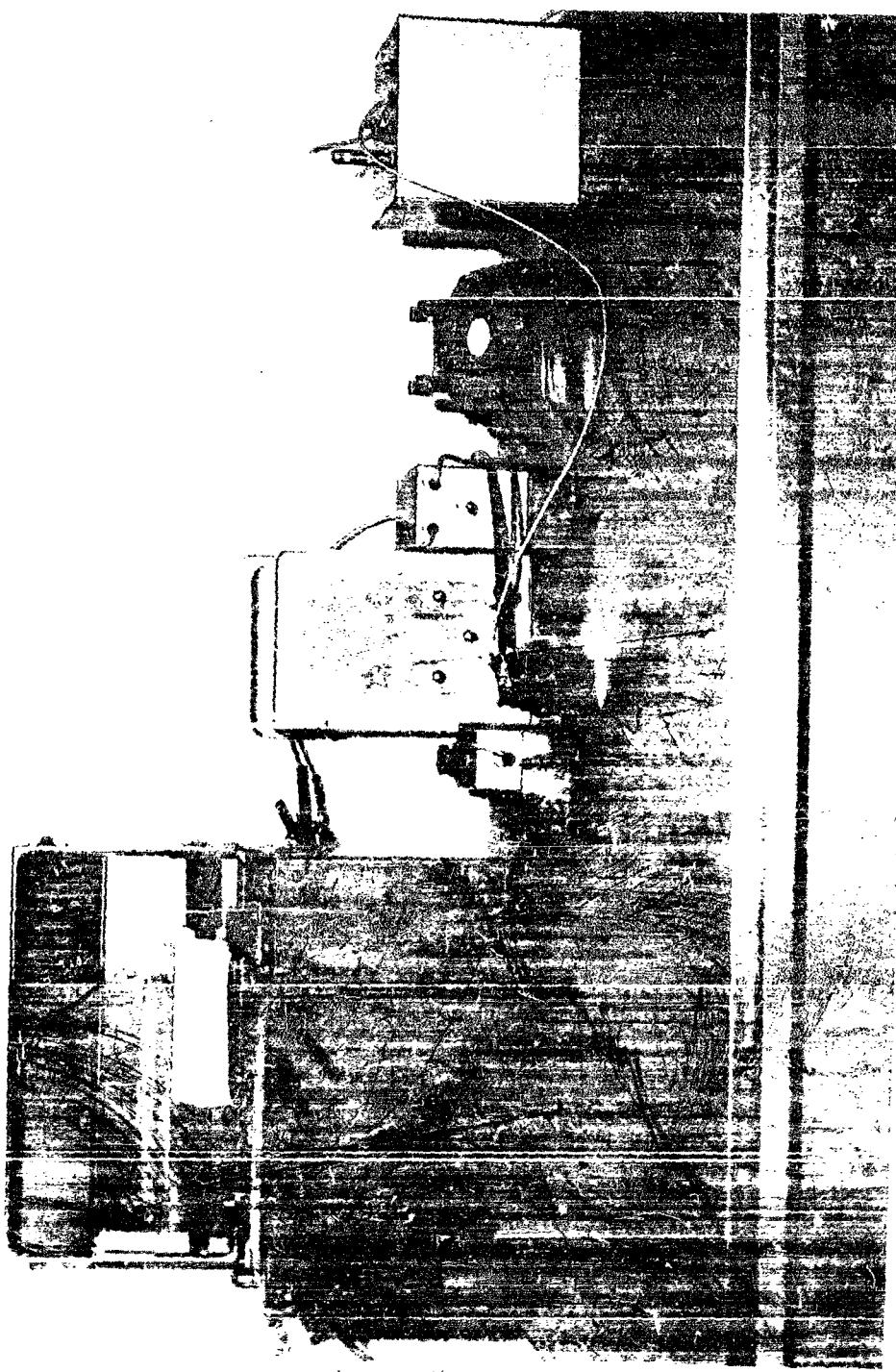


Figure 13 Telephone unit for transmitting ECG signals.

## BIOLOGIC EFFECTS OF HIGH ENERGY PARTICLES IN SPACE

By

Colonel Gerrit L. Hekhuis, USAF, MC

Colonel Hekhuis is Chief of the Radiobiology Branch of the Department of Medical Sciences, School of Aerospace Medicine. His professional education has included graduation from Yale University; M.D., University of Kansas; Post-graduate study in Radiobiology and Biophysics, University of Chicago; Radiology Residency, University of California Medical Center, San Francisco. He is certified by the American Board of Radiology. He is a rated Senior Flight Surgeon.

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School of Aerospace Medicine

By

Colonel Gerrit L. Hekhuis, USAF, MC

Particulate radiations to be encountered in the regions beyond the earth's atmosphere have been studied most extensively in terms of the general characteristics they exhibit when they, or their secondaries, reach the surface or lower atmosphere of the earth. These studies, since their first discovery prior to 1911, involving attempts to approach the origin of these rays by ascent of the Eiffel tower, and by means of increasingly higher altitude balloon flights, and more recently the data from earth satellite and deep space probes, have given us some information which allows at least a preliminary description of the types of cosmic radiations. Excluding any consideration of electromagnetic radiations such as may be present in space, this discussion will deal with the category commonly termed primary cosmic radiation. The description of the effects of these radiations will combine limited data from exposure of biological materials to cosmic radiations and to particulate radiations from man-controlled sources.

### I. Particulate Cosmic Radiation

It is practical, and in agreement with present viewpoints, to consider cosmic radiation to arise from two major sources. The first source, or grouping, of these radiations includes those which originate outside our solar system. They are designated galactic cosmic radiation, without specifying their origin within or beyond our own galaxy. The second source, or group, includes those radiations which originate or arise from our sun. These are designated solar cosmic rays, solar flare radiations, or solar winds.

a. Galactic cosmic radiations. Cosmic radiation of galactic origin is omni-directional, or isotropic, as observed from the earth. The intensity measured on the earth varies, and this variation exhibits a fairly regular periodicity of about eleven years, which is considered to be the effect of the magnetic activity of the sun-environment associated with its approximate eleven-year sun spot cycle. Additionally, the observed levels of the heavier primary rays reaching the earth varies markedly with latitude, and this effect is the result of the earth's magnetic field forces. For example, penetration to the earth's surface by a charged particle from space requires approximately 15 billion electron volts (bev) per nucleon at the equatorial plane and about 6 bev to enter and reach to 50 degrees latitude.

\*The contents of this paper reflect the personal views of the author and are not to be construed as a statement of official United States Air Force policy.

# Biologic Effects of High Energy Particles in Space

## Colonel Gerrit L. Hekhuis.

Beyond the effect of the sun-magnetism the original galactic cosmic rays are thought to be distributed fairly homogeneously throughout spaces, with local perturbations likely in regions of influence from magnetic field. The constituency of galactic cosmic rays is of the same order as the constituents of our known universe. The data of Brown and Winckler have been compiled by Tobias and Wallace (1) as shown in Table I.

TABLE I  
Abundance of Chemicals in Universe and Cosmic Rays

Atomic No. "Z"	Element Name	Atoms per $10^5$ Hydrogens	Relative Abundance in Cosmic Rays
1	Hydrogen	100,000	100,000
2	Helium	~7,700	15,500
3-5	Li, Be, B.	~0.1	240
6	Carbon	23	260
7	Nitrogen	46-200	? ~ 1200
8	Oxygen	63	260
10	Neon	2.6-7.0	30
12	Magnesium	2.5	40
14	Silicon	2.9	30
26	Iron	5	30
$Z > 10$		30	400
$Z \leq 30$ not listed		2.7	100
$30 < Z < 92$	~ 0.1		~ 10

Although differences in magnitude are present, the inference is that galactic cosmic rays consist essentially of representative elements of our universe, having been ionized, and accelerated to tremendous speeds. When the element composition of cosmic rays is compared to the elements present in our sun, the marked differences indicate that most of our relatively constant cosmic radiation has its origin in regions of space far beyond our sun.

The study of the energy distribution of the various particles shows some similarity of the spectrum, which has a bearing on the mechanism and mode of original acceleration of the particles. The observed data tend to favor those theories in which cosmic rays are accelerated in large bundles of plasma, or in shock waves, rather than the manner used in electrical accelerators. The lower energy limit of the energy spectrum of galactic cosmic rays seems to be about 100 million electron volts (Mev). The upper limit of electron

## Biologic Effects of High Energy Particles in Space 69

### Colonel Gerrit L. Hekhuis

contribution to the flux of primary cosmic rays is of the order of 1%, and the contribution of x- or gamma-rays to the total flux above the atmosphere is somewhat less than 0.1%.

b. Solar cosmic radiation. The second category of particulate radiations to be considered includes those of solar origin. This emission of particles particularly from areas of observed sunspot activity has been considered one of the main radiation problems of manned flight in space near the solar system.

Between 1942 and 1960 there have been five events in which marked increases in neutron fluxes were measured at the surface of the earth in various locations. These neutrons, not found in original cosmic rays, are totally produced as the result of secondary reactions produced in the air by the charged incident primary particles, and it is now established that these sudden increases in cosmic ray counting rate are correlated directly with solar flare incidence.

Solar flares are large chromospheric eruptions on the surface of the sun which may best be observed by the light of the hydrogen alpha line with a spectrohelioscope. Seen this way, an intense flare is one of the most fascinating and dynamic events within our sight. Large flares, perhaps one billion square miles in extent—similar to a sunspot area—consist of complex patterns of "white hot" filaments, suddenly blazing up to ten times normal brilliance in hydrogen light. They reach maximum intensity five or ten minutes after first appearance, and then decay or subside somewhat more slowly over the next couple of hours. Smaller flares are composed of bright patches, usually lacking the filamentous structures. Flares occur in conjunction with sunspots, being most frequent in the central regions of the groups, and less so at increasing distances, so that they are rarely seen more than 100,000 km distant from a sunspot (3).

Although the occurrence of a flare is as yet quite unpredictable the chances of one occurring are much greater with some types of sunspots than others. Flares are classified on a visual scale of importance, from class 1 (smallest) to class 3 (largest), plus a higher class 3+ category which is reserved for those of exceptional area and intensity. Table II, taken from Ellison (3), lists some of the characteristics of solar flares of the different classes.

# Biologic Effects of High Energy Particles in Space

## Colonel Gerrit L. Hekhuis

TABLE II

Flare Class	Area Range (millionths of sun's hemisphere)	Average Duration (min.)
1	100-300	17
2	300-750	29
3	750-1200	62
3+	> 1200	180

Flares not only emit light, they also send forth great quantities of particulate matter and energy from the sun. When the flare is brightest, great streamers of material, more intense than prominences, are seen leaving the chromosphere with velocities of up to 500 km/sec. (310 mi/sec). Some recorded movements are even at almost twice this speed.

Having identified and reviewed the two categories of particulate space radiation, let us compare the calculated and expected dose rates of radiation. Based on balloon and Pioneer V data, it appears that background galactic radiation in space may correspond to approximately (1 millirep/hr (1)). In the Van Allen belts, according to Schaefer (4), travel periods of about one hour would expose an astronaut to about 5 r for each passage trip. At three to four earth radii, the geomagnetic effects are somewhat minimized and the ambient galactic radiation amounts to about 25 millirep/day, or 9.5 rep/yr (1). The magnitude of the problem in the reach of a solar flare may be realized when calculations of the radiation to which an unshielded man would have been exposed in a 3+ flare as occurred on 10 May 1959 reveal an exposure dose in the order of 1500 rep (1).

### II. Effects

The radiation effects which are noted in most interactions of ionizing radiations with matter are those which result from the transfer of energy from the incident radiation to the matter traversed. This may sound simple, but the difficulty lies in describing the transfer of energy from the radiation to the system in which the effect is to be observed and measured.

The ratio of the biologic dose to the energy absorbed per gram involves the conversion known as relative biologic effectiveness, and this relation has been studied and reported extensively. This ratio is variable, and depends partially, at least on a) type of radiation,

71

**Biologic Effects of High Energy Particles in Space**  
**Colonel Gerrit L. Hekhuis**

- b) radiation energy, c) kind and degree of biological effects, d) type of biologic material, e) dose distribution total, time rate, and intervals, f) other factors such as temperature, oxygen, etc.

Excessive exposures to radiation can result in early acute changes such as nausea, vomiting, diarrhea, and fatigue, and higher doses to the entire body can produce death within days or weeks.

The radiation effects from single-exposure radiation to essentially the total body of a biological system seem to fall into a pattern that can be called an acute radiation syndrome. This pattern is essentially similar for various species of animals, although individual species show characteristic modifications which are a function of their own physiology. In man and the primate a very definite pattern of radiation-injury symptomatology occurs after a certain level of radiation dosage is delivered to the entire body in a single or short-term exposure. This acute radiation syndrome has been described adequately in the literature and is believed to be effective mainly at dose levels above 200 r total-body radiation.

Under 200 r total-body radiation a very small percentage of individuals exposed will show any effect of radiation, and these effects will usually be mild and transitory. At dose levels above 200 r, the severity of the radiation effect increases, and a greater percentage of the individuals is involved until finally, on a biostatistical basis, a radiation dosage can be reached at which all individuals can be expected to show changes. Some of these changes will produce death if the doses are high enough and the number of individuals exposed is large enough. Death may be the predominant result at very high doses. These changes are categorized in Table III.

TABLE III  
Acute effects, Total-body Radiation

< 200 r	No clinical significance
300-600 r	Hematopoietic depression and depletion
500 r	L-D 50%
600-900 r	Gastrointestinal form of death
> 1000 r	C. N. S. death; Incapacitation

These changes, described with reference to an administration of a single dose of radiation of varying levels of dose amount, are

## Biologic Effects of High Energy Particles in Space Colonel Gerrit L. Hekhuis

fairly well established. However, if the total dose administered is given over a period of time extending over two or three days instead of a single dosage exposure, the expected effect may be diminished from the pattern described by as much as from 25 to 30 per cent. Some of the effects observed may be reduced to even a greater degree. The radiation effect pattern or syndrome shows rather marked individual variation. It has been noted that the psychic effect of observing others exposed to the same radiation dose, such as has occurred in certain human population exposures, is also effective in increasing the observed effect in some individuals.

The effects of radiation may be fairly prompt or may be delayed by weeks, months, or even years. Classic examples of late effects of radiation have been reported repeatedly. Usually they are associated with degenerative changes in the tissue substance which culminate in failure of certain organ systems. The degeneration may be such that it allows the onset of an otherwise mild infection to become serious and even overwhelming. Other late effects may result in formation of tumors, alteration of life span, leukemia, and effects such as cataract formation in the lens of the eye, pigment change, hair-color change, and the like.

The evaluation of long-term effects or delayed effects of radiation is extremely difficult because of the requirement of observing significant numbers of individuals over a sufficiently long period of time and because of the necessity of having sufficient control of the population sample followed to assure that the effects noted are due to radiation rather than to other environmental factors. Since the effects noted are essentially similar, except in incidence, to those which normally may occur in the population observed, it sometimes is difficult to measure accurately the exact effect of radiation in the production of the end point noted. (5).

The application of this knowledge, or lack of specific details of the effects, to the biologic significance of cosmic radiation is particularly difficult and subject to much interpretation. Generally, the radiation observed or measured by each specific method rarely represents more than a minute portion of the whole radiation spectrum incident on any given biologic system or end point we have chosen as an indicator. Some primary cosmic particles terminate by a fairly regular dissipation of energy along a long track, and this type of termination is known as a thin-down. The far more common occurrence is the interaction of a high-energy primary with whatever material-- shielding, atmosphere, suit, biologic tissue-- it

## Biologic Effects of High Energy Particles in Space

Colonel Gerrit L. Hekhuis

73

encounters, to become a multitude of secondary radiations, each with its own characteristic range and rate of further ionization. Of the radiations encountered in space, the low energy heavy component of the primary cosmic category holds much interest because of the range of travel, and density of ionization produced in material to which the radiation is transferring its energy.

The depth to which primary particles may be expected to penetrate when expressed in gm/cm<sup>2</sup> is nearly the same in air, tissue and aluminum. When a heavy primary terminates by thin-down, it produces a characteristic microbeam of radiation pattern. As the particle slows to termination, the rate of transfer of energy increases, until just before termination, it reaches a sudden ionization peak. Table IV is an adaptation of data from Simons (6).

TABLE IV

Residual Range in Tissue in gm/cm <sup>2</sup>	Relative Energy Loss in Thousands of Ion Pairs/Micron Tissue
1.0	7.5
0.8	8.0
0.6	9.0
0.4	10
0.2	15
0.1	20
0.05	40
0.02	60
0.01	75

Secondary radiations produced by collisions of primaries (stars) and interactions with absorbing material (showers, and secondaries) are mainly composed of a) protons and neutrons plus b) mesons, and c) electromagnetic (x-) radiation. The neutrons and protons continue in their paths to collide with other absorber nuclei, producing new cascades of the three forms of secondary cosmic radiations. The rate at which these secondaries is formed is related to the shielding density and energy-reaction characteristics, and this knowledge is necessary in solving the problems of shielding. The various radiation events associated with different energy ranges of incident radiations are summarized in Table V. (7).

# Biologic Effects of High Energy Particles in Space

## Colonel Gerrit L. Hekhuis

TABLE V

Energy Range	Representative Radiation Events
$< 10 \text{ mev}$	Neutrons, beta, gamma, etc.
$10-300 \text{ mev}$	Spallation, fission, nuclear excitation followed by neutrons, protons, etc.
$300 \text{ mev} - 1 \text{ bev}$	Mesons, etc.
$> 1 \text{ bev}$	Mesons, electron- $\gamma$ , cascades, thin-downs for heavy primaries.
$> 10 \text{ bev}$	Buildup of secondaries.

From the previous general discussion, specific situations arising from exposure to cosmic radiations which may be of biologic concern include a) critical biologic volumes where local damage produced may be effective over greater ranges of volume or time, b) volumes of cells of critical control, unable to be regenerated or repaired if damaged, c) contribution to delayed effects.

Many specific changes as results of direct primary or secondary cosmic radiation have been reported; some have some correlation with dose or location of particle routes; other have negative correlation with similar factors. To date, no certain histologic delineation or outlining of a primary track has been made.

The possibility that a change in performance capability or behavior may be expected as the result of the reaction of a primary cosmic particle on the individual has been mentioned in connection with this radiation of a "critical volume." No present data establish the probability of such a major crisis as the result of primary cosmic radiation, but it is impossible to state that this type of event cannot occur. However, based on the experience of radiation of all portions of the body in therapeutic medicine, it appears unlikely that a major physiological or psychological interruption of function as the result of a single series of ionization events could occur. The evaluation of the exact hazard must await availability in our laboratories of particles of mass and energy comparable to primary cosmic radiations, and markedly improved techniques of experimental radiation location and measurement.

It is evident from the previous discussion that the estimation of the radiation hazard to biological tissue depends on many variables. This estimation must also be made in terms of the operation requirement of the exposure to the radiation.

## Biologic Effects of High Energy Particles in Space

Colonel Gerrit L. Hekhuis

75

Considering present knowledge, it is reasonable to suggest that a dose of 25 rad be permitted per operational space mission, with 25 rad to be reserved as an additional emergency dose, for error in orbit, unusual regions of radiation intensity, or an unpredicted solar flare. The estimation of the delayed effects of such suggested doses contains much uncertainty, but probably no more than exists in the combinations of vehicle reliability in launch, navigation, and return. The estimates considered to be reasonable are presented in Table VI (7).

TABLE VI

Radiation Dose vs Biologic Effect

Year:	1	3	5	10
Rad:	50	95	130	200
Leukemia	3x	6x	9x	12x
Longevity	?	2	1	1-2 yr
Sterility	0	0	0	?
Cataracts	0	0	0	0
Genetics	2x	3x	4x	5x

The biologic effect of radiation is no single effect, nor is the effect specific for radiation. Similar effects can be produced by other agents or combinations of agents. Also, the biologic effect observed in any one individual is peculiar to that individual both in degree and time response. The degree of hazard must be evaluated not only in its own right, but in comparison with other hazards that are also involved in the life situation and in the operational requirements.

The viewpoint of persons concerned with control and interpretation of radiation exposure must be based on education, experience, and understanding. Radiation must be considered essentially as an additional factor of hazard in one's life, on the ground, in the atmosphere, or in space. By itself, radiation is not the limiting factor to human participation in progress (8).

## Biologic Effects of High Energy Particles in Space Colonel Gerrit L. Hekhuis

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## PHYSIOLOGIC NECESSITIES IN SIMULATED LUNAR FLIGHTS

By

Billy E. Welch, Ph.D.

Dr. Welch is Chief of the Space Ecology Branch, Department of Space Medicine, School of Aerospace Medicine. His professional education has included graduation from Abilene Christian College; M.S., and Ph.D., Texas A & M. For several years he conducted research in Environmental Physiology at the Medical Research and Nutrition Laboratory, Fitzsimons Army Hospital. Other professional experience included work as a physiologist at Northrop Aircraft Corporation.

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# PHYSIOLOGIC NECESSITIES IN SIMULATED LUNAR FLIGHTS\*

79

By

Billy E. Welch, Ph.D.

The primary purpose of including man in a space mission is to utilize man's full and unique capabilities toward successful mission completion. This means, therefore, that the man portion of the space mission must be at maximum effective performance consistent with the mission profile. To insure that man will be at maximum effectiveness, it is necessary to satisfy the various physiologic requirements that man places on the space vehicle system. These physiologic requirements are not necessarily unique to space operations and, for this discussion, will be classified somewhat arbitrarily into atmospheric and metabolic requirements. This paper will be divided into two parts; the first consisting of a brief discussion of the physiologic necessities and the second consisting of data collected during space-cabin simulator experiments.

## PART I

### ATMOSPHERIC REQUIREMENTS

The choice of an atmosphere for a manned space vehicle or manned space station is of critical importance to the astronaut and is governed by many considerations, both physiological and engineering in nature. The first, and, of course, the most obvious solution to the problem of atmospheric composition is to provide the space crew with an atmosphere that duplicates the one that is present on earth. With the exception of a few notable geographic locations, this is an atmosphere that is very acceptable to man and one on which most information is currently available. There are, however, other conditions that can be considered in fulfilling man's atmospheric requirements, if necessary, from the mission profile aspect. Table I shows the various atmospheric requirements that man places on the space vehicle along with the maximum range of each parameter that could be considered for possible use.

Pressure - The maximum range in total pressure is from 760 mm Hg to approximately 187 mm Hg, with the lower pressure limits being regulated primarily by the need for maintaining alveolar oxygen levels. At 187 mm Hg and in an atmosphere of pure oxygen, approximately 100 mm Hg partial pressure of oxygen is maintained in the alveoli, the remainder of the lung being filled with carbon dioxide and water vapor.

\*The contents of this paper reflect the personal views of the author and are not to be construed as a statement of official United States Air Force policy.

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

The use of pressures less than 760 mm Hg apparently provides some bends protection (Balke, 1959; Marotta and Marbarger, 1961) in the event of decompression (both accidental and intentional). This aspect of atmospheric selection could be of tremendous importance if a mission profile is such that the astronaut is required to leave the confines of his spacecraft and perform useful work outside.

Oxygen - The tolerable range in oxygen partial pressure is more restrictive than that for total pressure. The minimum level is, of course, governed by the need for sufficient partial pressure of oxygen to maintain blood oxygen saturation levels. The upper level appears to be a toxicity limit and, according to Luft (1952), this limit is in the range of 400-425 mm Hg partial pressure. Michel, et al (1960) have demonstrated this in a group of six men exposed to a total pressure of 523 mm Hg ( $p_{O_2}$  of 418 mm Hg) for a period of seven days. It is interesting to note that even though the manifestations of this oxygen toxicity have been described many times (Becker-Freyseng and Clamann, 1943; Comroe, 1945; and Bean, 1945), the exact mechanism of action remains to be elucidated.

Another aspect of the use of higher levels of oxygen (i.e., 100% oxygen at less than toxic partial pressures) is the possible occurrence of atelectasis during both static and dynamic situations. This has been reported by Klocke and Rahn (1960) in experiments where the absorption of oxygen from the lung was measured during breath-holding. The effect of this phenomenon on tolerance to acceleration also has been investigated by Hyde (1961) and has been found to decrease "g" tolerance by a significant amount.

Carbon Dioxide - The partial pressure of carbon dioxide poses a serious problem to the safety of the crew and the health of the crew members if allowed to accumulate in the cabin. The current thinking is that carbon dioxide should not be allowed to exceed 7 to 8 mm Hg partial pressure. There has been one long duration experiment conducted by Fauceett and Newman (1953) however, in which 23 men were exposed to 11 mm Hg partial pressure of CO<sub>2</sub> (total pressure 760 mm Hg) for a period of 42 days. No deleterious effects were noted, although there were signs of a definite adaptation, characterized by a mild respiratory acidosis and a decreased sensitivity to higher levels of CO<sub>2</sub>.

Temperature and Relative Humidity - Any consideration of temperature should include relative humidity and vice versa, since these environmental parameters are closely related, particularly in terms of physiologic tolerance. In general, a dry bulb temperature of 70-75 degrees F. and a wet bulb temperature of 60-65 degrees F. is

Dr. Billy E. Welch

considered desirable. Consideration must be given, however to air density, clothing, level of activity and time of exposure. Clothing should be particularly emphasized, due to the impact that poorly ventilated pressure garments can have on man's effectiveness and subsequent tolerance to other stresses.

Micro-contaminant Levels - The problem of defining permissible levels of various micro-contaminants in the micro-climate of a space vehicle is one of the more challenging problems confronting the scientist and engineer today. Guidelines for many compounds are available in the form of maximum allowable concentration (MAC) data. This suffers one large deficiency, however, in that the MAC assumes a prescribed, intermittent exposure, whereas in the spacecraft, exposure will be on a continual basis. In addition, exposure in the spacecraft might be at pressures other than atmospheric and could be complicated by interactions of compounds or, as pointed out by Ebersole (1960), by the breakdown of relatively non-toxic compounds into highly toxic ones. The sources of contamination in a spacecraft are and will be numerous. They include the crew members, life support subsystems, waste disposal systems, paints, fires, motors, etc. The possible sources of contamination are, therefore, many and the utmost care must be used to insure that micro-contaminants do not become a limiting factor in the habitability of the astronaut's ecological system.

## METABOLIC REQUIREMENTS

The metabolic requirements of the astronaut also must be analyzed carefully in order to insure that these requirements can be adequately satisfied. Table II shows these requirements, which include energy, oxygen, water and liquid and solid waste management. The astronaut's energy requirement represents one of the more critical areas of interest in the study of man in space, since a difference in 300 to 400 kilocalories per day requirement can amount to 125 to 150 pounds of food and oxygen per man-year.

It might appear odd to include liquid and solid waste management in a grouping of metabolic requirements, but in a sealed cabin, these two items can assume tremendous importance and exert considerable influence on the atmosphere control and conditioning system.

## PART II

### SPACE CABIN SIMULATOR EXPERIMENTS

#### Methods

The space cabin simulator used in the experiments described here was the two-man space cabin simulator that has been described

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

In previous lectures (Welch, 1961). Figure 1 shows a schematic of the simulator which is physically located in a small, insulated room. This room effectively isolates the simulator from normal ambient noises and enables contact with the crew members to be restricted to intercom type communication.

A total of five experiments, each of 17 days duration, will be considered. The purpose of these experiments was to examine the influence on man of living at reduced barometric pressure and in atmosphere predominately consisting of oxygen. A 17-day duration was selected in order to provide data collected over a period of time that exceeds presently contemplated mission durations, e.g., APOLLO. Four of the experiments were conducted at a pressure altitude of approximately 190 mm Hg with an oxygen partial pressure of approximately 174 mm Hg. The fifth experiment was conducted at ground level pressure and 156 mm Hg partial pressure of oxygen. The complete environmental data are shown in Table III.

All subjects were volunteers and were current in single engine jet aircraft. Physical examinations and pre-flight baseline values were obtained during a two-week period prior to the flight. Post-flight values were obtained during a one-week period following the experiment. In addition, the in-flight schedule (Table IV) was arranged in such a manner that various in-flight physiological measures could be obtained daily, alternating between a relatively basal morning and a fasting, resting evening sampling for each man.

Food was supplied predominately in the form of pre-cooked, dehydrated food. In all flights but 17-5 (190 mm Hg experiment), the water supply was obtained by the on-board vacuum distillation of urine and cabin atmosphere condensate. In 17-5, the water supply was distilled water.

Solid wastes were either removed from the simulator through a small air lock (17-1, 2 and 3) or were stabilized by a vacuum-heat dehydration process (17-4 and 5).

### Results and Discussion

The primary data reflecting the influence of the atmosphere composition and confinement on the crew members are the post-flight physical examinations compared to the pre-flight results and the in-flight pulmonary function data. In general, the post-flight physical examinations have been essentially negative, indicating little or no

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

83

immediate influence of the atmospheric composition and confinement in the simulator on the crew.

Physical performance of all ten subjects as a group, assessed by the constant speed, variable angle treadmill test of Balke (1952) was not affected by the 17-day confinement as indicated in Figure 2. There was wide variability to the exercise test with individual responses being both positive and negative. This result does not agree with previously reported data from a 30-day experiment (Welch, 1961) nor with the results reported by Graveline and Balke (1960) following a 7-day water immersion experiment.

This comparison can be extended to the assessment of the cardiovascular system by orthostasis (Figure 3). Orthostatic tolerance was determined pre and post-experiment by rotating the subjects from a horizontal position to a vertical position and measuring blood pressure every minute for seven minutes in the vertical or passive standing position. There appeared to be a slight decrease in pulse pressure following the 17-day experiments but tolerance to orthostasis was not altered. The slight drop in pulse pressure definitely was not to the extent reported following the hypodynamic experiments (4-6 mm Hg pulse pressure).

No oxygen toxicity symptoms per se were noted following the experiments conducted at 190 mm Hg and an oxygen partial pressure of 174 mm Hg. X-rays taken 10-50 minutes post-flight were also negative, although arterial oxygen saturation levels taken immediately following or preceding the x-ray indicated some physiologic shunting of blood consistent with but not diagnostic ofatelectasis as shown in Table V. These values were obtained by pre-breathing each man for 5-10 minutes with 100% oxygen prior to obtaining the arterial blood sample.

In-flight pulmonary function measurements have not shown any alterations that do not appear to be directly attributable to the effects of reduced pressure. A brief summary analysis of tidal volume, vital capacity and maximum breathing capacity is shown in Table VI. The in-flight results from the four experiments at altitude are consistent, showing, when compared to pre-flight values, an increase in both tidal volume and maximum breathing capacity and a decrease in vital capacity. Duplicate measures of vital capacity did not show any significant differences.

The caloric intake data is shown in Table VII. It should be noted that the pre-cooked, dehydrated food was supplied on an ad libitum basis in an amount to provide in excess of 3,000 Kcal/man/day.

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

The only stipulation placed on food consumption was that any package opened must be consumed in its entirety. Measured caloric intakes ranged from 1721 to 2585 Kcal/man/day with an average intake of 2110 Kcal/man/day. The per cent of the diet composed of carbohydrate, fat and protein was 55.1%, 31.2% and 13.7%, respectively.

Body weight changes were observed in both a positive and negative direction as measured by a daily calibrated "bathroom-type" scale. If this body weight change were tissue with a caloric equivalent of 4 Kcal/gm, the measured caloric intakes could be adjusted (Table VIII) to yield a corrected range in caloric intakes from 1919 to 2851 Kcal/man/day with an average of 2283 Kcal/man/day. Expressed more definitively in terms of initial body weight, this would be 32.0 Kcal/Kg body weight/man/day. This level of activity could be compared to light work as defined by DuBois et al., 1960 (cited by Buskirk, 1960) in which the peak tasks are approximately five times the basal level.

The relationship between total body weight change and caloric intake expressed as Kcal/Kg body weight/man/day is shown in Figure 4 by the x's. The correction of the caloric intake data for weight change is also shown in Figure 4 (circles). It is apparent that the 4 Kcal/gm correction value was reasonably accurate as indicated by the vertical relationship of the corrected values.

The water use data are shown in Table IX and averaged 1766 ml/man/day ranging from 2236 to 1322 ml/man/day. The 1766 ml/man/day was used for drinking (1231 ml/man/day), for food rehydration (380 ml/man/day) and for personal hygiene (145 ml/man/day). It should be noted that all water and urine data were obtained by the test subjects as they recorded the volume, time and use of water and the volume of urine produced.

Calculated water balance data are shown in Table X. Water available to the body including water preformed in food and metabolic water averaged 1936 ml/man/day. Average daily water output in urine and feces was 1030 ml/man. If the body were in water balance, this would yield a calculated insensible water loss of 906 ml/man/day.

In all experiments but 17-5, recycled water formed approximately 80% of the water consumed. No obvious difficulties have been noted in the consumption of this water and subject acceptance has been good.

### Summary

This discussion of man's physiologic necessities of simulated lunar flight should be considered applicable to actual space flight

## **Physiologic Necessities in Simulated Lunar Flights**

**Dr. Billy E. Welch**

85

situations. Undoubtedly, the dynamic aspects of the flight, complete with the various emotional aspects and actual isolation from the mother planet will alter the picture somewhat. This possible or probable alteration, however, means that man's requirements should be identified as clearly as possible in simulators in order to better plan for space flight and to identify the effects of actual flights.

### **ACKNOWLEDGEMENT**

The authors wish to express their appreciation to the many people that helped make these experiments possible. In particular, the cooperation of the SAM Consultation Services Division and the many physicians who volunteered their services in these studies should be noted. It is also a pleasure to acknowledge the efforts of the many technicians that have assisted in the program.

**Physiologic Necessities In Simulated Lunar Flights**

Dr. Billy E. Welch

**TABLE I**  
**MAN'S ATMOSPHERIC REQUIREMENTS IN A SPACE VEHICLE**

Pressure Control	760-187 mm Hg
Oxygen Partial Pressure Control	425-100 mm Hg
Carbon Dioxide Partial Pressure Control	8-0 mm Hg
Temperature Control	75-70 degrees F
Relative Humidity Control	60-40%
Micro-Contaminant Control	Non-Toxic

**TABLE II**  
**MAN'S METABOLIC REQUIREMENTS**  
**IN A SPACE VEHICLE**

Energy
Oxygen Supply
Water Supply
Liquid and Solid Waste Management

**Physiologic Necessities in Simulated Lunar Flights**

**Dr. Billy E. Welch**

**87**

**TABLE III  
SUMMARY OF ENVIRONMENTAL CONDITIONS**

	17-1	17-2	17-3	17-4	17-5
Total Pressure (mm Hg)	190	195	191	748	193
Oxygen Partial Pressure (mm Hg)	176	173	173	156	175
Carbon Dioxide Partial Pressure (mm Hg)	3.0	4.0	3.0	1.2	2.9
Temperature (degrees C)	21.4	18.8	20.8	23.7	21.8
Relative Humidity(%)	50	77	55	57	52

**TABLE IV  
SIMULATOR FLIGHT SCHEDULE**

TIME	SCHEDULE I	SCHEDULE II
0700-0900	Medical Testing	
0900-1100	Psychomotor	
1100-1300		Psychomotor
1300-1500	Psychomotor	
1500-1700		Psychomotor
1700-1900	Psychomotor	
1900-2100	Medical Testing	
2100-0200	Sleep	Psychomotor
0200-0700	Psychomotor	Sleep

**SUBJECTS ALTERNATE SCHEDULES EVERY 24 HOURS**

**Physiologic Necessities in Simulated Lunar Flights**  
**Dr. Billy E. Welch**

**TABLE V**  
**ARTERIAL OXYGEN SATURATION (%)**

Flight	Subject	Pre	Post
17-1	1	*	94.9
	2	91.8	88.2
17-3	5	97.3	100.7
	6	99.9	90.1
17-4	7	96.0	100.0
	8	97.0	99.0
17-5	9	97.3	100.0
	10	98.4	101.0

\*No pre-flight data

**TABLE VI**  
**PULMONARY FUNCTION SUMMARY**

Function	Pre-Flight vs In-Flight	P
Tidal Volume	(7)*	0.01
	(1)	ns
Vital Capacity	(7)	0.01
	(1)	0.05
Maximum Breathing Capacity	(8)	0.01

\*Number in parenthesis = number of subjects.

**Physiologic Necessities in Simulated Lunar Flights**

**Dr. Billy E. Welch**

89

**TABLE VII**

**AVERAGE DAILY CALORIC INTAKE**

Flight	Subject	Initial Weight (Kg)	Average Daily Intake (Kcal)	Average Daily Intake (Kcal/Kg Body Wt)
17-1	1	71.0	1980	27.9
	2	66.0	1929	29.2
17-2	3	68.2	1922	28.2
	4	78.5	1957	24.9
17-3	5	74.7	1721	23.0
	6	89.8	2050	22.8
17-4	7	59.5	2549	42.8
	8	75.5	2387	31.6
17-5	9	68.2	2016	29.6
	10	65.7	2585	39.3
AVERAGE		71.7	2110	29.9

90 **Physiologic Necessities in Simulated Lunar Flights**  
**Dr. Billy E. Welch**

**TABLE VIII**  
**AVERAGE DAILY ENERGY REQUIREMENT**

Flight	Subject	Weight Change (Kg)	Average* Caloric Req. (Kcal)	Average* Caloric Req. (Kcal/Kg)
17-1	1	-0.91	2188	30.8
	2	0	1966	29.8
17-2	3	-0.45	2088	30.6
	4	-1.82	2436	31.0
17-3	5	-2.50	2370	31.7
	6	-3.18	2851	31.7
17-4	7	+1.13	2245	37.7
	8	+0.45	2236	29.6
17-5	9	+0.45	1919	28.1
	10	+0.23	2530	38.5
Average			2283	32.0

\*Corrected for weight change, assuming 4 Kcal/gm of weight change.

**Physiologic Necessities in Simulated Lunar Flights** 91

**Dr. Billy E. Welch**

**TABLE IX**

**AVERAGE DAILY WATER USE DATA**

Flight	Subject	Drink (ML)	Food Dehyd. (ML)	Pers Hyg (ML)	Total (ML)
17-1	1	1400	538	127	2065
	2	1545	403	136	2084
17-2	3	872	194	256	1322
	4	1106	187	386	1679
17-3	5	881	437	66	1384
	6	1045	388	345	1778
17-4	7	1060	430	0	1490
	8	1229	481	22	1732
17-5	9	1466	354	74	1894
	10	1710	493	33	2236
Average		1231	390	145	1766

92 Physiologic Necessities in Simulated Lunar Flights  
Dr. Billy E. Welch

TABLE X  
AVERAGE DAILY WATER BALANCE DATA

Flight	Subject	Available to Body* (ml)	Excreted by Body** (ml)	Water Balance (Avail-Exc) (ml)
17-1	1	2220	1008	1212
	2	2240	1374	866
17-2	3	1371	687	684
	4	1605	777	828
17-3	5	1563	854	709
	6	1724	769	955
17-4	7	1864	1121	743
	8	2055	1211	844
17-5	9	2116	1093	1023
	10	2603	1405	1198
Average		1936	1030	906

\*Includes liquids consumed, water added to food, water in food and water formed by oxidation.

\*\*Includes water in urine (average 960 ml/man/day) and feces (average 70 ml/man/day).

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

93

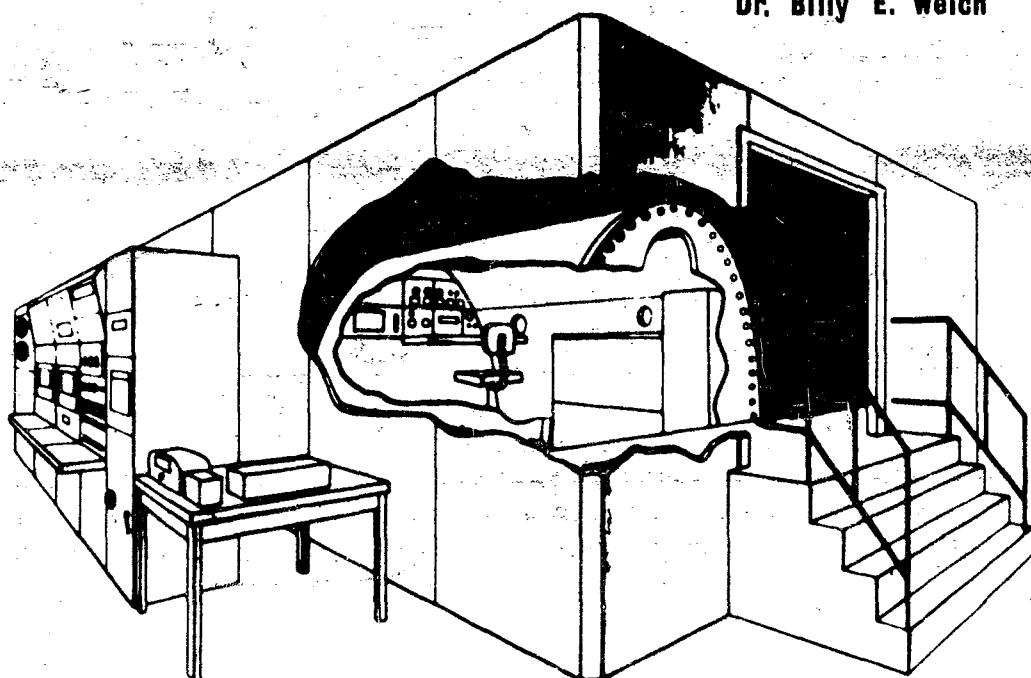


Figure 1. Schematic of Simulator.

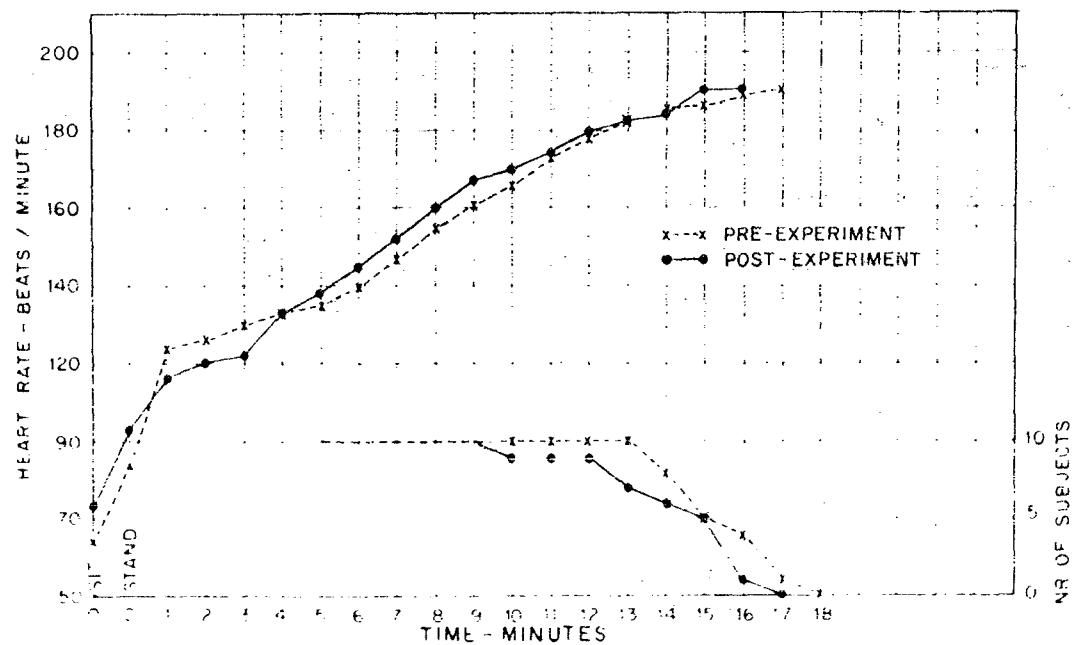


Figure 2. Average Exercise Tolerance.

**Physiologic Necessities in Simulated Lunar Flights**

Dr. Billy E. Welch

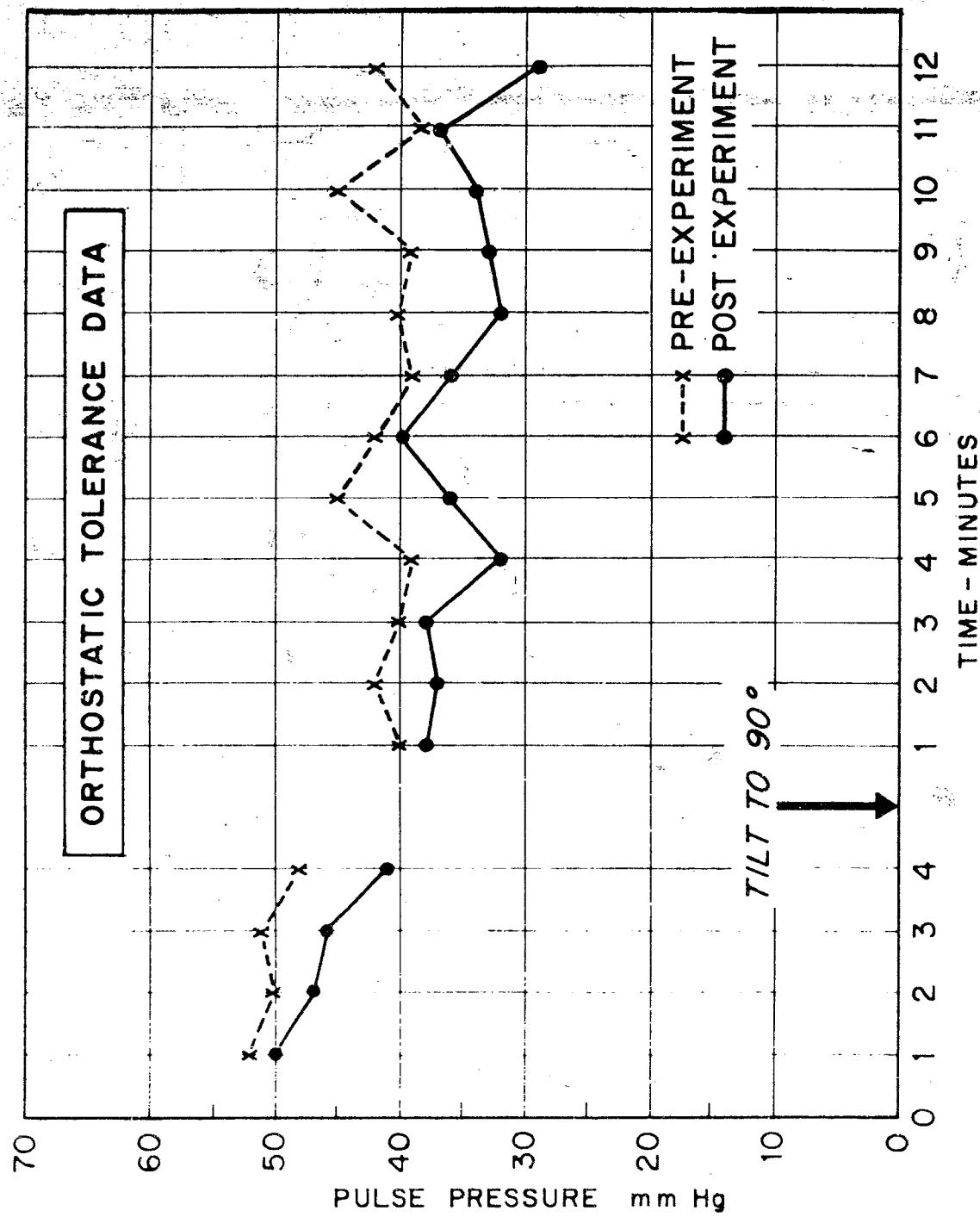


Figure 3. Average Orthostatic Tolerance Data.

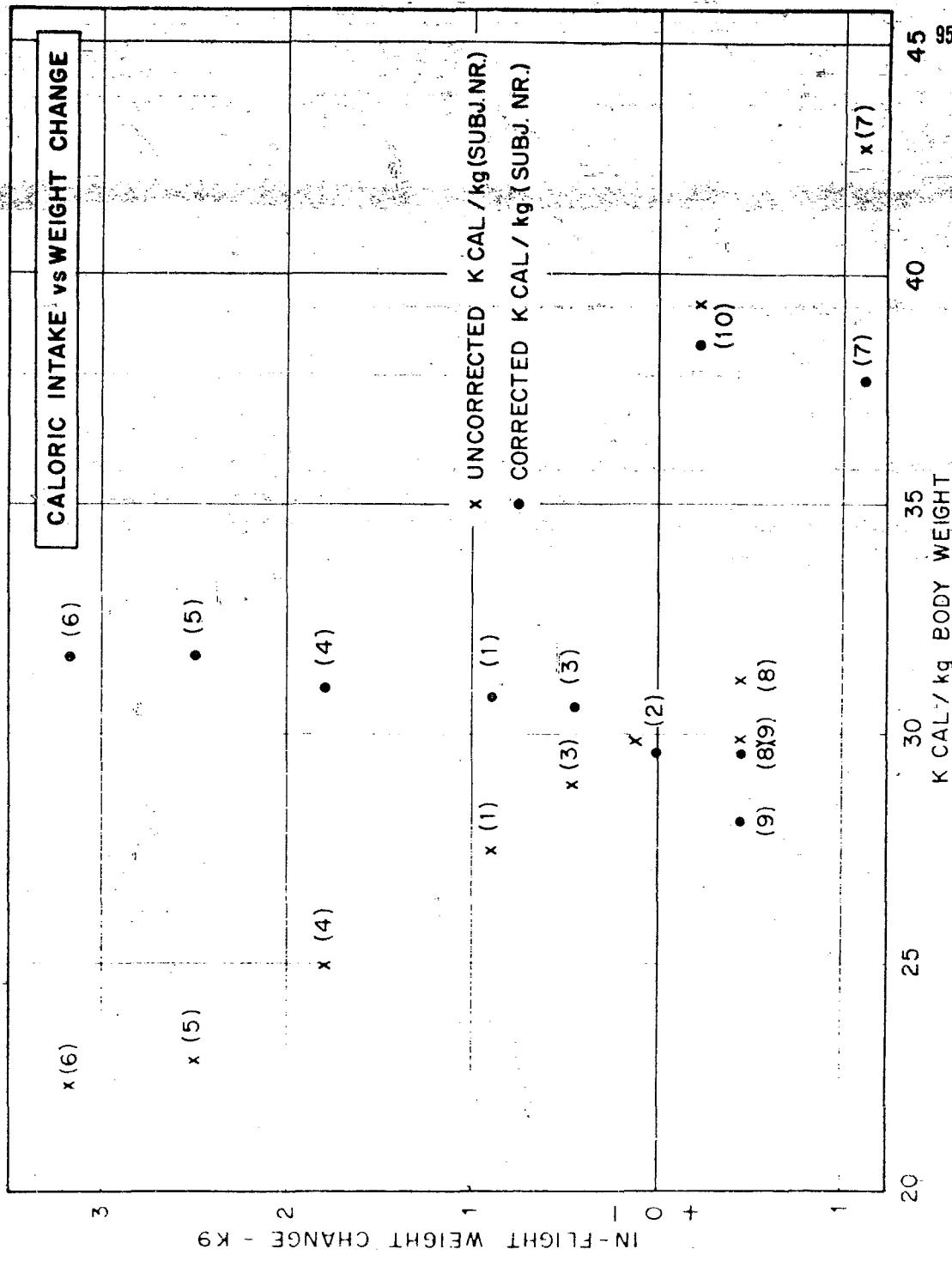


Figure 4. Caloric Intake vs. Body Weight Change.

## Physiologic Necessities in Simulated Lunar Flights

Dr. Billy E. Welch

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## BIOMEDICAL MONITORING IN-FLIGHT

By

Captain James A. Roman, USAF, MC

Captain Roman is Chief of the Biodynamics Branch, Department of Space Medicine, School of Aerospace Medicine. He earned his B.S. in Mechanical Engineering at Northwestern University, and his M.C. at Western Reserve University. He served as a Research Flight Surgeon at the Aeromedical Laboratory, Wright-Patterson AFB. He is a rated pilot and Flight Surgeon.

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# BIOMEDICAL MONITORING IN-FLIGHT\*

99

By

Captain James A. Roman, USAF, MC

"Biomedical Monitoring" means different things to different people. For the operational situation in space, biomedical monitoring implies the automatic gathering of quantitative information relative to physiological functioning in the intact human or animal in a form suitable for evaluation, recording, or storage. The term "physiological" is used here in its very broadest sense.

Automatic monitoring of physiological parameters relies at this time heavily on electronic techniques and for this reason has been with us a relatively short time. Pioneering efforts at biomedical monitoring were seen in high altitude balloon flights, both by the United States Navy and the United States Air Force, and in the course of animal experiments in rockets at Holloman Air Force Base in the early 1950's. The next few years will see monitoring techniques used on a large scale in the course of space flight, of flights in high performance vehicles, and on hospital patients.

The advent of semi-conductors and the relative ease with which miniaturization may be accomplished in circuits employing them accounts only partly for the interest in biomedical monitoring and the strides which we have witnessed in the past three years. Sophisticated schemes for monitoring physiological information in an operational situation were entirely possible with vacuum tube techniques. The impetus for the recent rapid progress in monitoring techniques has been provided by the advent of manned space flight. In what follows we will concern ourselves largely with biomedical monitoring as it applies to space flight.

## WHY MONITOR PHYSIOLOGICAL INFORMATION?

Many of the mission profiles currently being contemplated in space lend themselves to modification after launch, should an in-flight emergency arise. Typical of such profiles are certain orbital flights in which as a result of an in-flight emergency of one kind or another, re-entry at other than the scheduled time might have to be contemplated. The decision might then present itself as to whether to re-enter immediately and accept as a result recovery in an area not best suited for that

\*The contents of this paper reflect the personal views of the author and are not to be construed as a statement of official United States Air Force policy.

## Biomedical Monitoring In-Flight Captain James A. Roman

purpose, or else continue the orbit until such time as recovery could be accomplished under more favorable circumstances. Many types of emergency calling for such a decision could affect the environmental system or even the crew directly. Under such circumstances knowledge as to how the crew was tolerating the changed environment from the physiological point of view might contribute heavily to the operational decision.

In the past, many types of high performance vehicles including research vehicles have been lost without a clear knowledge as to the cause of the catastrophe. In some of these cases incapacitation of the crew was suspected. However, the question could not be answered as to what part, if any, the physiological status of the crew played in the final result. The cost and effort involved in physiological monitoring is so small compared to the cost of launch for a space mission that uncertainty as to the physiological status of the crew in a hostile environment may no longer be accepted as part of the operational situation.

In justifying the use of biomedical monitoring as part of the space mission, the arguments presented above have been used in the past with few references to fundamental physiological research. Necessity dictates, however, that biomedical monitoring in early manned space efforts be used also for purposes of fundamental physiological research and that it be justified partly on that basis. This necessity stems from the fact that man's physiological tolerance to the space environment cannot be determined in the laboratory with the same ease and completeness that such tolerance could be investigated for atmospheric flight. Man's environment in flight in the atmosphere, including the gravitational environment, has been simulated and investigated in the laboratory in most respects except possibly for the "stress" phase. In the space environment, man's physiological functioning in four important categories is not amenable to investigation in the laboratory at this time. The design of future space vehicles and mission profiles will depend to a large extent on the evaluation of physiological data gathered in the course of our early space efforts. The main environmental conditions which we can at the present time not simulate in the laboratory are these:

(1) Prolonged weightlessness: Simulation of some of the effects of weightlessness is being accomplished by techniques such as water immersion. The extent to which these conditions duplicate the physiological effects of prolonged weightlessness is unknown. Validation of these techniques will only come about when sufficient physiological information is collected under condition of actual weightlessness.

Every indication to date points to prolonged weightlessness as a potent factor in altering physiological functioning in man.

(2) Prolonged acceleration between 0 and 1 G: This situation will be found in space craft if and when artificial gravity is employed and will be seen in any case on the surface of certain planets, such as the moon. The same remarks apply here as apply to prolonged weightlessness.

(3) Radiation: The radiation environment of space is incompletely mapped out at the present time as regards both the intensity and the nature of the radiation encountered. Exact laboratory simulation of the radiation environment is not feasible at this time.

(4) "Stress": As has been demonstrated in high performance aircraft (Figures 1, 2), physiological functioning during critical phases of flight is at least quantitatively different from that seen in the laboratory. This results from a combination of factors, such as alertness, which are here loosely grouped into the term "stress". The physiological reaction referred to here is apparently a bona fide response to a difficult and threatening situation rather than to the physical environment. Simulation of this response in the laboratory is difficult, impractical, or impossible. It is not anticipated that physiological functioning for the entire course of a space mission will be dominated by "stress" effects. Rational evaluation of physiological data telemetered during critical phases of the mission, however, will depend upon the monitor's knowledge and familiarity with such effects.

The justification for the use of biomedical monitoring on space missions is thus seen to be based on considerations of operational safety and on the need to gather data which will bear on the design of future space vehicles and mission profiles. The considerations which apply to biomedical monitoring are seen to be precisely those which have led to the monitoring of engineering parameters from high performance vehicles and space craft. Biomedical monitoring need not in the future be justified as a separate entity. The reasons which compel us to monitor engineering variables from space craft apply in their entirety to biomedical monitoring. Just as the evaluation of data telemetered from space leads to a constant redesign of the engineering components of a space vehicle, so the evaluation of physiological data will lead to modification of human tolerance by means of protective devices such as those which have made atmospheric flight possible for the crew.

## Biomedical Monitoring In-Flight Captain James A. Roman

### THE STATE OF THE ART

The state of the art in biomedical monitoring is determined by the degree of success that has been achieved in three distinct and important areas:

- (1) The choice or the development of physiological parameters, the monitoring of which will yield useful and specific information.
- (2) The development of small, light and reliable sensors with which to monitor these variables.
- (3) The development of techniques for interpretation of physiological information which will allow for a maximum of information to be derived from measurements made in flight.

The foregoing is simply a way of stating that physiological parameters for use in biomedical monitoring must be chosen in such manner that information derived from them is unequivocally interpretable as well as being descriptive of the functioning of important organ systems. In addition, the choice of parameters must be governed by the knowledge as to whether or not reliable sensors exist with which to measure them or whether such sensors can be developed within the near future.

At the present time the parameters shown in the right hand column of Table 1 could be monitored in a fairly practical way in the in-flight situation. It is seen that 12 channels of telemetry or on-board recording are required, of which 9 channels must be wide band channels and 1 channel must be a very wide band channel. At the present time at the School of Aerospace Medicine only the 3 parameters shown in the left hand column are being monitored routinely and in what follows it will become clear what lead to the choice of those 3 parameters.

- (1) The parameters shown on the left can be measured with a great deal of reliability. The weight penalty involved in obtaining them is small. The total system shown on the left, assuming that compressed gas is available aboard the vehicle, amounts to less than 10 lbs. Further, sensors for monitoring these three parameters are reasonably practical and small.
- (2) These parameters, in contrast to some shown in the right hand column, are unequivocally interpretable and it is not likely that

they will be interpreted in different manner by different observers working under the pressure of an operational situation.

(3) Last, and probably most important from the operational point of view, operational go-no-go limits, even though very wide, may be set for each crew member for these parameters.

The combination of the 3 parameters shown on the left gives us a rough estimate of cardiorespiratory performance with minimum weight penalty. The information derived is suitable for very rapid evaluation and for presentation to the monitor in a simple and straight forward fashion. Failure or marginal function of the circulatory and in some cases the respiratory system is certain to be indicated and at times predicted from an interpretation of these three parameters. Correlation of information derived, with vehicle parameters and environmental variables is certain to yield highly meaningful information upon which to base the design of future mission profiles.

In a much more sophisticated system, such as the one shown on the right, it is clear that the weight penalty would be great. In addition, sensors adequate to record all these parameters would encumber the astronaut in a significant way. Third, because of the larger number of sensors and the relatively embryonic state of development of sensors for certain parameters, reliability of this system would be low. And last, our knowledge of the interpretation of the physiological parameters shown on the right hand side is such that as regards the cardiorespiratory system little significant information would be gained over and above that derived from our simple system. The information derived from the two parameters (EEG and GSR), describing certain facets of the operation of the central nervous system, would not be unequivocally interpretable. The large cost of television in terms of band width and weight might well be justifiable on other grounds but not on the basis of physiological information derived from examining a television picture.

A short review of the state of the art as it concerns each parameter should serve to solidify the points made above.

(1) ECG. Electrocardiogram is usually obtained at the present time by means of a single lead (sternal) consisting of 3 electrodes, each of which is less than 1/4 inch in diameter and less than 1/8 inch in height. These sensors do not require shaving. Artefact free tracings are obtained which allow the measurement of heart rate, the detection of arrhythmias, and the detection of gross myocardial damage. A small increase

**Biomedical Monitoring In-Flight****Captain James A. Roman**

in reliability and interpretability is obtained by adding another lead necessitating a total of 5 sensors on the thorax. (4) Obtaining vectorcardiogram components of laboratory quality would necessitate a total of 4 leads with a total of 13 electrodes if reliability were to be maintained. The interpretation of vectorcardiogram components today is not as unequivocal as the interpretation of a single sternal lead, and in addition, a vectorcardiogram of laboratory quality is not likely to be obtained on an active subject. For that reason, as well as because of the increased cost in terms of wide band channels, recording of vectorcardiogram routinely during space flight is not advocated at this time.

(2) Blood Pressure. The electrocardiogram will give indications of certain types of physiological decrement. However, marginal cardiovascular operation and indeed cardiovascular collapse may present itself in the presence of a near normal electrocardiogram. Blood pressure in this respect is extremely valuable. It is unlikely that cardiovascular collapse will be overlooked in the presence of ECG and blood pressure information. The reliability of the blood pressure apparatus developed and used at SAM is such that blood pressure is likely to be readable under the most difficult conditions anticipated during space missions (3, 2). Blood pressure measurement at this stage requires an occluding cuff and it is hoped that an equivalent measurement will be obtained within the near future without the use of such an occlusive device.

(3) Quantitative Respiratory Flow. The type and the intensity of linear accelerations encountered during space missions make it extremely desirable that pulmonary ventilation be monitored in some way. When the crew is wearing an oxygen mask or when the pressure suit face plate is closed, it is possible to record quantitative respiratory flow by simple means. This will give an indication of the onset, either of hyperventilation or of inadequate pulmonary ventilation. In the shirt sleeve situation or in those instances when the pressure suit face plate is open, measurements are limited to respiratory rate. This information is not nearly as useful as quantitative respiratory flow. Very high respiratory rates may occur in the presence of inadequate pulmonary ventilation. Quantitative measurement of respiratory flow in the shirt sleeve environment is not a reality today, although it is hoped that impedance plethysmography will solve that problem for us in the near future.

(4) Pulse Velocity. The interest in pulse velocity has been revived during the past year in the hope that a solid relationship between blood pressure and pulse velocity could be established. Should such a relationship be determined, then the need for an occluding cuff

in obtaining blood pressure would no longer exist and blood pressure measurement on long space missions would become much more practical. The magnitude of the pulse velocity is determined, not only by the blood pressure, however, but also by the physical properties of arterial walls. Under different physiological situations these properties have been known to change. It is unlikely that pulse velocity can be related to blood pressure under all circumstances. In some preliminary work done in flight it appears that pulse velocity can be related to blood pressure. However, this has been observed under a very restricted set of physiological conditions, that is, fairly high peripheral resistance. It is unlikely that the same correlation will hold true either on the treadmill or in the heat chambers. In view of this, some now advocate the use of pulse velocity as being descriptive of certain phases of cardiovascular function without necessarily any relation to blood pressure. An ambitious laboratory program is necessary in order to determine the place of pulse velocity measurements in biomedical monitoring for space flight.

(5) Heart Sounds. Heart sounds can give ancillary information concerning cardiovascular function. In addition, the presence of a large amount of fluid in the alveoli would probably be detected by a cardiac microphone. Since there exists some doubt as to how well fluids will be handled in the pulmonary tree during weightlessness, the measurement of heart sounds has more than one factor to recommend it. Heart sounds, in addition, are quite easy to measure and require only a very small sensor. This sensor could be combined with an ECG electrode.

(6) EEG. From a clinical point of view, much information can be derived from the electroencephalogram. It is especially useful in pathological states. In the normal individual, it will among other things give a rough estimate of the level of consciousness. When more subtle differentiations are to be made between levels of consciousness or the state of awareness, then the interpretation is not likely to be as uniform among different observers. When one couples these facts with the consideration that EEG potentials are fully one order of magnitude smaller than ECG potentials, then it becomes apparent that monitoring EEG under space flight conditions is not warranted by the amount of information to be derived from it, especially on early flights. EEG, however, remains as one of our best hopes for monitoring the central nervous system and an ambitious laboratory program to perfect both EECG techniques and EEG interpretation is justified at this time.

(7) GSR. The remarks which apply to ECG apply to a great extent to GSR. Here again, an ambitious laboratory program is

## Biomedical Monitoring In-Flight Captain James A. Roman

needed to eventually rule GSR either in or out of biomedical monitoring for space flight.

In the preceding discussions, it is assumed that voice is available, and it is also assumed that environmental parameters are being monitored. Regarding voice, it is obvious that if only one channel were available for monitoring, it would have to be voice. However, experience in high performance aircraft, especially experience relating to hypoxia, makes it quite clear that the crew member is a very poor observer of physiological happenings in himself, especially in case of an emergency. As was seen in the course of flights during World War I in which hypoxia was almost a daily occurrence on certain missions, it is possible for a crew member to function marginally in a physiological way for hours at a time without being aware of it except for a vague recollection of ill feeling and subsequent feelings of tiredness and malaise. Regarding environmental parameters, it should be clear that a rational evaluation of physiological parameters monitored from a space vehicle is impossible without a knowledge of the environment. Values for heart rate, blood pressure or respiratory flow which would be well within acceptable limits in a certain environment might be indicative of a large decrement in physiological performance given an other, slightly different environment.

### INTERPRETATION OF DATA

Interpretation of physiological data gathered in flight bears many obvious similarities to interpretation of data gathered in a clinical situation. The most important difference in interpretation, however, between the clinical and the in-flight situation is that, in the course of space flight, the environment will in all cases be radically different from that under which our clinical baseline norms were gathered. In the course of space flight, the crew will be subjected either to high linear accelerations, or else it will be weightless, or nearly so. In addition, the gaseous environment is likely to be quite different from that seen in the clinical situation, even if environmental systems are operating properly. Diet and fluid intake is likely to bear significant differences to that seen in the clinical situation and, finally, the level of alertness or "stress" during critical parts of the mission will be widely different from that under which patients are normally examined.

The preceding simply points out that if we are to rationally evaluate data gathered in the course of space flight we must arm ourselves with new "norms" as a background from which to make our judgment. Values for heart rate, blood pressure or respiratory

flow during boost and re-entry can be determined, and to a great extent have been determined, on the centrifuge. However, a large body of data remains to be gathered on early space flights relative to cardio-respiratory or other norms in the weightless environment. During states of heightened alertness such as exist during critical phases of X-15 missions and in our F-100 research aircraft at the School of Aerospace Medicine, physiological functioning has been shown to be at least quantitatively markedly different from that seen in the clinical situation. As a result, existing clinical norms for blood pressure and heart rate are all but useless to us in the inflight situation. Figures 1 and 2 make this point very clearly. In Figure 1 the composite heart rates for 4 X-15 flights are shown (1). Neither the level nor the direction of the resultant accelerations are shown on these graphs and it is safe to say that some of the increase in heart rate is due to accelerations above 1 g, both transverse and positive. However, the magnitude and the duration of accelerations encountered do not begin to account for the heart rates seen here. It should be kept in mind that clinical norms for heart rate are all below the level of the abscissa on this graph. Heart rates such as these could not be reproduced in the non-exercising patient under clinical circumstances without the use of drugs. Figure 2 shows the respiratory rates for 4 X-15 flights. When it is kept in mind that the normal respiratory rate is approximately 16 per minute, this figure will be seen to illustrate again the fact that clinical norms are inadequate in the in-flight situation. Admittedly, X-15 flights are particularly exciting as well as being very short, and certainly one would not expect values such as these for long periods of time during space flight. Figure 3, however, shows a plot of blood pressure and heart rate during F-100 flights, averaging approximately 2 hours. The results of 10 flights are shown as can be seen from the heart rate plot, these flights were not particularly exciting ones. Indeed, most of these were under VFR conditions and severe weather was encountered only for a very short portion of one flight, at altitude. Yet it is seen that the blood pressures, especially diastolic, are almost entirely outside the range of clinical norms. Such blood pressures, when seen on clinical patients, would carry with them a grave prognosis. Here again, the necessity for obtaining new norms becomes quite evident. Regarding interpretation of data in biomedical monitoring then, three points are made:

1. Physiological baselines must be gathered for the in-flight situation.
2. Work done in our research aircraft at SAM indicate that for each individual subject there are certain characteristic blood pressures and heart rates for different phases of flights.